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ADVANCE NOTES ON RESEARCH

The Editor will be pleased to receive advance notes on research results for publication in the Journal. Such notes need to be no more than 200–300 words in length.

CORRECTION NOTICE

In the paper "Studies in the digestibility of herbage. IX. Herbage and faecal nitrogen as indicators of herbage organic matter digestibility", by D. J. Minson and C. D. Kemp, *J. Brit. Grassl. Soc.*, 1961, **16**, 76–9, the symbol **D** was used to represent the digestibility of the organic matter in herbage. This symbol had previously been used to represent the percentage content of digestible organic matter in the dry matter of herbage ($\mathbf{D} = 100 \times \frac{\text{Feed O.M. eaten—Faeces O.M.)}}{\text{Feed D.M. eaten}}$, in *J. Brit. Grassl. Soc.* 1960, **15**, 174–80, and in *Proc. 8th Int. Grassl. Congr.*, 1960, 470–4, both papers by D. J. Minson, W. F. Raymond and C. E. Harris. A different symbol, D, should have been used in *J. Brit. Grassl. Soc.*, **16**, 76–9, for the percentage digestibility of herbage organic matter.

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THE BRITISH GRASSLAND SOCIETY IN THE WORLD OF TOMORROW*

WILLIAM DAVIES, D.SC. (WALES), HON.D.SC. (N.Z.)

The inaugural meeting of this Society was held at Stratford-on-Avon in June 1945 under the Presidency of Sir George Stapledon, whose passing we sadly mourn today. We have thus been in operation as a Society for nearly 16 years. After getting away to a good start in 1945 we have since been able to consolidate our position both numerically and financially. The Society is closely wedded to matters pertaining to grassland but pays attention also to animal and soil problems. Witness to this is the fact that we have had joint meetings with the British Society of Soil Science, and the British Society for Animal Production. I hope we shall continue to hold joint symposia with societies whose interests impinge upon our own, for it is important that we maintain a width of both agricultural and scientific interest if we are to make the full use of our resources.

The Society offers a cross-section of interests, its members including farmers, technicians and research workers mainly from this country but also from abroad. The Journal has been successfully launched and is now established as a scientific periodical with some 700 subscribers apart from members of the Society. The Journal is therefore well consolidated on an international basis, and through it the Society speaks with authority.

Through the Journal we have maintained scientific interest, while our summer meetings have enabled us to strike a balance of interest between science and practice. We have played our part in the international field through our overseas membership, and it was also to the B.G.S. that H.M. Government delegated the task of organizing the 8th International Grassland Congress, the successful outcome of which has added to national prestige as well as to that of the Society.

County Grassland Societies. An interesting recent development has been the foundation of regional Grassland Societies in Britain. The new Societies desire affiliation with the B.G.S. and it is our clear duty to do all we can to foster the new movement. The B.G.S. can provide the meeting point for County Societies and also assist their integration into one national whole. We must play our part and will surely welcome new County Societies wherever they may be formed.

The new movement creates, however, something of a problem for the B.G.S. because our activities in the long term will be judged by technical achievements. We must jealously safeguard our Journal as the mouthpiece of research and of advanced grassland practices, thereby setting a standard internationally acceptable.

County Grassland Societies must follow a more practical approach, keeping themselves fully informed about current advances in agricultural science. They face the most important of tasks, namely to integrate fresh knowledge and the new techniques of science into practice in an ever-changing economic environment. The B.G.S. and the County Societies, therefore, have complementary roles, and given the goodwill which happily already exists, the new movement could provide all-round benefits to the grassland/livestock industry in Britain.

Until now the formation of new County Grassland Societies has been the result of local initiative. Henceforth the B.G.S. can take more positive action to encourage new Societies and to offer guidance when required. Preliminary arrangements have already been made to ensure that representatives of existing County Societies shall meet periodically under the Chairmanship of the current President of our Society. This is surely an excellent arrangement which I suggest should continue.

There are a number of well established Grassland (sometimes called 'Pasture')

*Presidential address, delivered at the Winter Meeting of the British Grassland Society, London, 9 December 1960.

Societies overseas with whom it might be very profitable for us to establish a link. During the 8th Congress in Reading some of us met informally, so that we now know where at least some of these are located. Many countries of the Commonwealth, including some of those in Africa and Asia, have as yet no Grassland Society. I believe it to be important that there should be Pasture Societies in all Commonwealth countries, because grassland is essential, frequently providing the raw material on which more than half the national product is based. The B.G.S. could provide the focal point for existing Grassland Societies and for new ones. It might even encourage its overseas members to take the initiative to form Grassland Societies in territories where none exist at present. This Society has already taken a leading part in the affairs of the 8th International Grassland Congress, and should continue to be represented at future International Grassland Congresses and to offer any assistance within its power.

There is another need that still remains, namely the interchange of young scientists between this and overseas countries, and the establishment of scholarships which would make it possible for grassland research workers to spend periods of from three months to two years in overseas study. This applies particularly to the age group 30–40 and after 5–10 years of active research experience after leaving University. This is an expensive time in the life of most individuals and while sabbatical leave can often be arranged, the expense of transporting wife and perhaps young family is of such magnitude that the individual is unable to take advantage of normal scholarship or travel grants. I suggest this Society should consider this matter, and perhaps it could sponsor an acceptable scheme. Its influence, together with any financial aid which might be possible, would be of the utmost importance and might ensure that the present gap is bridged adequately.

Grassland Diploma. The award of a grassland diploma by the B.G.S. could have important repercussions on grassland productivity in this country. Grassland recording may ultimately provide a reasonable basis for the diploma award. Awards of this kind would encourage the pioneer and accelerate the integration of new techniques into existing practice. I do not suggest that such a diploma should be limited only to practice, but the emphasis should be on the stimulation of new practices.

Grassland Recording. From its earliest days the Society has focused attention upon the practical problems associated with pasture evaluation and animal production from grass. This led to the formation of the Committee whose valuable report was published in the B.G.S. Journal (1955). Evidence on this topic was sought by, and given to, the Caine Committee which, in its report, endorsed the need to establish a simple but reasonably precise method for grassland recording on the farm. An effective form of recording is certainly necessary if we are to evaluate grass as a diet for cattle and sheep in relation to animal husbandry as a whole.

Recently the British Grassland Society, the Milk Marketing Board, the Surrey and Sussex County Grassland Societies and The Grassland Research Institute have taken grassland recording a step further. A programme of developmental research is in operation which could lead to simple systems of farm recording. It is important that we give every possible support to this development and ensure its success.

The B.G.S. has now attained maturity and has so consolidated its position, both nationally and internationally, that it can formulate with some authority practical programmes for the benefit of the grassland/livestock farmer. The Society has an enormous background of both practical and technical experience which could be used in formulating grassland policy. One aspect of this problem must always be in the forefront of our thinking, namely the demands to be made on our grasslands and the level of output for which we shall aim, always in relation to potential. The "potential" needs periodic revision as new research findings become available and find their levels in practice. It might be one of the functions of the B.G.S. to review targets from

time to time and to lead the industry in setting new targets.

I want to review briefly the position at which technology and leading practice find themselves in this country and to suggest the kind of target at which the grassland farmer could aim during the course of the next decade. I do this from the standpoint of present knowledge and what may follow from pointers provided by current scientific work being applied to grassland.

Henceforth it is necessary to evaluate with precision grass as a food, using the saleable animal product as the yardstick of worth. The potentials of climate, of soil and of physical input (e.g. fertilizers) must be known and put to full use within a biological environment embracing plant and animal, the latter including the human element. Modern, and especially intensive, systems of grassland farming are not for the uninitiated. The intensive use of grass involves decisions which need skill and demand an intimate knowledge of both animal and plant reactions. By comparison the equally intensive arable cropping systems appear to be relatively simple.

The basic approach of the livestock farmer to the use of grass as animal feed rests upon the comparative cheapness with which grass can be grown in this country. As feed it is least expensive if grazed with no harvesting and storing costs. Because of the seasonal nature of plant growth it is unlikely that we shall ever be rid of either periods of shortages or periods of excess growth. Therefore we will always be faced with grass conservation and its problems. This, however, does not reduce the need for doing all we can to minimize the influence of dry weather in summer or of low temperature and/or low light intensity during winter. Therefore, the extension of the number of weeks during which grassland makes active growth within the calendar year must provide one of our major approaches. We must not, however, disregard other ways of using grass and of feeding animals, and must examine the possibilities of systems such as storage feeding which may involve concentration of cattle and sheep in feed lots or under conditions akin to those employed in the new broiler industries.

There is still, however, a great deal that can be done to extend the grazing season. This will differ from environment to environment, in relation to systems of farming and type of livestock enterprise. It seems more difficult for the dairy farmer to make use of pasture in winter than for the beef producer, and it is still easier for the sheep farmer to do so. Again, the difficulties of the clay land farmer are greater than those on lighter soils. The average grazing season has been greatly extended in this country since 1940 and there are many situations in Britain where it is possible to graze sheep and cattle for the whole 12 months. If pasture, adequate in both quantity and quality, were available under these conditions, there seems no reason why the grazing animal should not be at production levels throughout the year. Quality of pasture diet is probably the most urgent problem so far as outwintered animals are concerned, although in most situations the quantity of pasture is also limited in winter and in many districts also during the driest weather of summer.

Indigenous species and varieties provide reasonably adequate feed of good quality and thus cover the summer period very well. Improved techniques and the use of the new varieties make possible a grazing season extending from March to November, a total of some 30–35 weeks. If we are to extend still further the grazing period, it will be necessary to seek for new varieties among exotic grasses. Fortunately, such materials exist and we must look at them carefully. We know that certain Mediterranean forms of tall fescue, cocksfoot and other grasses from the sub-tropics show considerable potential for growth during winter. We can take advantage of this feature in relation to local environment, manuring and soil management. The hunt for new materials is on and will continue, because this can be very important when defining future potential. The story is only at its beginning and one task will be to collect further material so that the plant breeder has a wider range of genetic variation which can be used as the basis for new varieties.

We know a good deal about the use of fertilizers. It is now accepted that to make the most of grassland it is necessary to use lime, phosphate and potash in adequate amount. There is less agreement with regard to nitrogen. "Bag" nitrogen is available in quantities as never before, but we are still in controversy as to whether to use more fertilizer nitrogen on our pastures, or whether to foster the legume and thereby obtain the nitrogen from biological sources. This is basically a matter of economics and it would seem that within the extensive systems under which most British grassland is farmed today, there is a strong case for relying on the clover rather than on bag nitrogen. However, the use of additional nitrogen for specific purposes, such as for production of grass in early spring and late autumn, is necessary even when the aim is a so-called balanced grass/clover sward. On the small livestock farm, however, grassland production has to be more intensive. In this case, fertilizer must provide the major source of nitrogen, so that legume N becomes more or less incidental. At the present time, grassland manuring and management on the small farm too often mirrors that on the large farm. This just cannot be, for essentially the small farm must rely on high output per acre if it is to provide a reasonable income, whereas the large farm can rely on a lower output per acre and still provide an adequate living.

We must look at our fertilizer programmes not only in terms of Ca, P, K and N but also the whole range of plant nutrients. Trace element deficiencies have been recorded in Britain, often exhibited more by the animal than by the pasture. For example, certain cases of copper deficiency in the animal can be related to diet; also grass tends as a feed to be short of magnesium. There may be other minerals in short supply inhibiting plant growth as well as animal performance, as in Australia. The evidence as regards the place of the trace elements in our normal fertilizer programmes is still, however, fragmentary, but there is enough of it to show that this line of enquiry might prove fruitful, notably perhaps in moorland reclamation, and within the context of intensive systems of grassland use under lowland conditions. Situations also arise which indicate excess of certain minerals; a classic example in this country is molybdenum excess on the "teart" pastures of Somerset and elsewhere. Excess of potassium in herbage causes ill-health in the animal without showing obvious symptoms in the plant. Grasses and legumes take up potash at "luxury" levels seemingly without adverse effect upon the plant, but leading to dysfunction in the grazing animal. This may be toxicity or an imbalance of minerals (calcium, magnesium and sodium are involved). The practical point is that the intensive grassland farmer may have to guard against excessive use of potash.

The dietary value of grass very heavily fertilized with nitrogen is also in question on the scores of both palatability and nutritive value. The N content of green leaves is increased by heavy dressings of fertilizer, and the fact that most herbage as grazed during the spring and summer in this country contains amounts of nitrogen in excess of animal requirements suggests that we might consider carefully and put to critical test the dietary value of herbage of low, medium and very high nitrogen content. Much of the N in young rapidly growing leaves is likely to be in forms other than the proteins characteristic of more mature plant tissues. Some of this nitrogen may be in nitrate form and can accumulate in leaves if the uptake of N is at "luxury" levels. Dysfunction and death do occur in animals grazing on herbage of this type, although the precise mechanism is as yet not understood.

Grassland management is a term widely used by all of us during the past 40 years. It might be rewarding to review what is meant by good grassland management. Some regard good management as that which is good for grass. This point of view is frowned upon by the animal husbandryman, who insists that good grassland management must be synonymous with good stockmanship as concerns grazing animals. These concepts need to be brought together, and they can be married, for both views have right on their side. My view is that good grassland management is the nicking together of plant, animal and soil in such a manner that high production of grass is

attained on a continuing basis, i.e. within a single season and in successive years. This should be accompanied by such quality in the grass diet as to be adequate at each grazing to cater fully for the needs of the thrifty animal of high potential production. A consequence of this, and one that forms an integral part of good management, is the improvement in soil potential and in crop-yielding capacity taking the rotation as a whole. Good grassland management, therefore, leads to high yields of herbage and to high values of animal output from grass, which in turn enhance the fertility of the soil.

We already know something of pasture management. There is still need for investigation of many problems associated with the use of grass and of intensified systems of growing and using it. Some are primarily associated with producing more grass of predetermined quality and of sufficient uniformity to cater for the day-to-day requirements of the productive animal. Others are more directly associated with the use of grass, aiming at greater production of food for cattle and sheep. Within each of these contexts I would stress all those factors related to the variation in food value and also to animal reactions (thrift or dysfunction) when afforded grass as the only diet.

Quality in herbage (offered as a "menu" to the ruminant animal) must basically determine its value measured by thrift in the animal. Most herbage plants when in active growth contain minerals in adequate quantities for normal production in the grazing animal. There may be exceptions, such as cobalt or copper. Some minerals may commonly be at high levels in herbage, as in the case of N, or seasonally at excessive levels, as in the case of K. Grass as we know it in Britain has an energy value usually adequate for maintenance and for some production in the meat and milk animal, but may fall short in energy requirements for the animal at nutritional stress (the milk cow at peak of production, for instance).

It should be possible to improve the energy value of grass consumed by the animal. The sugars and other water-soluble constituents of herbage have a high energy value, and it may prove possible significantly to increase their proportion. It seems, for example, that ryegrass is richer than cocksfoot in soluble sugars. The digestibility of herbage is higher when young than when old. Actively growing herbage is usually of high digestibility and its content of soluble sugars may be higher during sunny weather than in cloudy conditions. This indeed may explain in part why grazing animals thrive better when the summer is dry and sunny than they do in wet and comparatively sunless seasons.

One of the consequences of our present methods of using grass is the serious losses incurred between the time when the crop is grown and the time when it is utilized by the animal. These losses are much greater than is commonly recognized, and may well amount to an overall loss of two thirds of the total. This implies that only about one third of the solar energy trapped by grass-land plants is ultimately available for the animal. It is important, therefore, to know just when and where these losses occur and to prevent them. This involves a study of both grazing management and grass conservation. There are large losses involved in the making of hay and in the grass ensiling process. Prof. S. J. Watson has recently indicated that the average losses in grass silage made experimentally are of the order of one fifth of the dry matter, one third of starch equivalent and three quarters of the digestible crude protein fractions. These data are based on experimental work where care would usually be taken to reduce the losses. It is likely, therefore, that under normal farm conditions the wastage is very much greater.

There is much wastage also on normally-grazed pasture land, due to insufficient grazing, accumulation of patches, including those associated with animal excreta, and also those due to leaf fall at periods of rapid growth and during times when grass fields are rested, as in hay, silage and foggage production. Some of this waste, during grazing and also in the processes of conservation, may be unavoidable, but we should re-examine this whole problem because the present losses are so great that they cannot be tolerated within efficient systems of grassland utilization.

The hill lands of Britain form a large section (some 45% of the total) of our grasslands which is completely under-developed. The B.G.S. could play an important part in bringing pressure to bear upon the national conscience so that more is done to move forward work, both practical and scientific, in regard to our hill country. Much has already been done scientifically by, for instance, the Welsh Plant Breeding Station and The Hill Farming Research Organization. There are pioneers such as Sir James Denby Roberts and Captain George Bennet Evans who have tackled hill improvement successfully. In addition there is much marginal land on the valley slopes all over Britain, some of which have been reclaimed since 1945. By and large however, the extensive plateaux at elevations between 1000 ft. and 1500 ft. have not been tackled on any substantial scale. Some of the skills for improving these lands are known, but further research and experiment are required. The problem of hill improvement must, however, be tackled nationally, for it is only partly a grassland/animal problem; it is also a forestry problem and one of sociology designed to make the hills accessible by road improvement, the creation of new roads, and by improving all kinds of services including water, housing, electricity and drainage. These developments to be accomplished need time and require considerable outlay of capital. The prize, however, would be a major extension in the size of the national livestock farm. The hill lands need well-planned systems of shelter belting. The steeper land on the hills and valley sides could well be planted to forest trees and the whole landscape could be integrated, perhaps on the basis of Sir George Stapledon's proposals for national parks to provide valuable holiday grounds that could offer facilities for fishing, walking, riding and mountaineering. In this way some measure of relief would be given to our already overcrowded seaside resorts. The hills at least would provide an alternative pleasure ground for the holiday-making public.

It is easy to extend the list of benefits which an improved pastoral agriculture holds for Britain and which would lead to the better use of our natural resources and provide a better living for all. For example, material benefits would accrue if sheep and cattle could be freed from bowel parasites. We know that ruminant animals when free from these are more thrifty and better producers. If planned on a national scale it should be no more difficult to attain nematode-free animals than it has been to attain tuberculosis-free cattle. Again the concept of multiple litters in the ewe and of twinning in cattle through appropriate stock management coupled with hormone treatments need be no more a "pipe dream" than was A.I. a couple of decades ago. The scientific breeding of herbage plants in the modern sense is less than 50 years old. Selection has to a large extent been based on morphological characters, including leafiness and the ability to produce tillers in profusion. Henceforth the breeder can select for physiological characters associated with quality and we shall no doubt find new indices of quality, some of which may prove to be heritable.

These are a few of the new developments which represent the prizes that the farmer of the future may know as commonplace. It is research and technology, always the handmaids of progress and the major tools of forward-looking communities, which make these advances possible. I believe it is one of the important duties of the B.G.S. to make its position so secure and its influence so great that it can mould opinion and direct national effort in such a way that the research demands of the grasslands of this country will be met with full advantage to the farming industry itself and to the nation at large. As a Society we have an important part to play and knowing the vigour of the B.G.S. I feel confident that this Society will, over the years, play it in full.

THE RANGE—NATURAL PLANT COMMUNITIES OR MODIFIED ECOSYSTEMS?*

R. MERTON LOVE

Chairman, Department of Agronomy, University of California, Davis

Range research and its application in the United States have been primarily in the area of ecology. The guiding principle developed is that the natural plant communities (the climax vegetation) provide the best guides to forage production potential.

A careful study of man's history from the Ice Ages to the present reveals the fact that man has progressed by modifying his environment. In fact, the ability to do so is one of the significant differences between man and other animals. During the last 10,000 years man has been in turn a collector and hunter, a cultivator and domesticator, and finally an industrial agriculturist. The transition has been a slow, laborious process.

The mixed-oak forests of the Mediterranean and Europe were cleared by felling and burning the trees and cultivating the cleared ground by crude flint hoes. In his migrations man learned of differences in soils and adaptations of cultivated plants. He learned to work with nature, but he also learned how to overcome some of nature's limitations.

Agriculture, then, is man's attempts to overcome nature's limitations so that a desired crop can be grown and harvested. By this modification of the environment the crop supersedes the pattern of natural vegetation. There is no intrinsic difference between range and intensive agriculture, since both involve factors inherent in climate, soil, plants and harvesting.

Ecologists working in the field of range management must be willing to accept ideas and principles that have put more science in the "science and art" of farming, if the "science and art" of range management is to progress sufficiently to make possible the realization of the vast potential of our ranges and wild lands.

Man is making tremendous advances in the physical sciences and in many of the social and biological sciences (Stakman (41)). Research workers in these fields are not satisfied to rely on the "truths" that have been propounded in the past. They are continually exploring new ideas and applying newly developed facts to their problems. Can the same be said for research workers and administrators in the "art and science of range management"? Our expanding population is demanding more and more from our ranges, wild lands, and watersheds. It seems appropriate at this time to explore the development of range management principles, placing them in their proper perspective in the history of man's development, and to outline some of the possibilities for improving the vast resources that our ranges constitute.

Norman J. Berrill (2), Strathcona Professor of Zoology, McGill University, has written a delightful book called "Journey into Wonder". It traces the explorations of Columbus, Hawkins, Drake, and Dampier in the Caribbean and Central America, and the ocean voyages of Cook, von Humboldt, Darwin and others; and they are described not as history, adventure, or travel, but as rewarding investigations into natural history and science.

One point that Berrill makes is that with each new voyager "a new unsullied mind has seen the world in a fresher light than the last, has been called by adventure and returned in wonder". A point of no less importance is that the conclusions drawn from the experiences of some early explorers, Columbus and his men, for example, were based on too little, or false, information. "What is of interest," writes Berrill, "is that a question that seemed to have been settled once and for all is again thrown open to inquiry". And he adds, "I find a lot of

*Revised from an address presented at a plenary session of the American Society of Range Management and American Grassland Council, Tulsa, Oklahoma, January 1959, entitled Range Management Today and Tomorrow.

satisfaction in the thought that none of our answers is truly final".

In the preface to Part I of "Plough and Pasture—the early history of farming," we find the following statement: "Origins, causes, principles—these are the important things if we are to see our civilization in true perspective; and we cannot look into the future with sound judgement until we have acquired a balanced understanding of what has gone before" (Curwen, (13)).

On the basis of the thoughts expressed by Berrill and Curwen—that none of our answers is truly final, and that to look ahead with good judgement we must understand what has gone before—I want to explore the subject "New Frontiers in Range Improvement". Let me take you back through the distant past, to the stumbling beginnings of man's farming endeavours, to learn a little of the "origins, causes, and principles" referred to by Curwen. In this way, I hope to show you where rangeland farming stands in the scheme of things today.

Apart from theft or plunder, we obtain our food in three ways:

(1) hunting, fishing, and gathering wild fruits, leaves, and roots—food gathering, a very precarious existence;

(2) cultivating certain plants and domesticating certain animals—peasant culture;

(3) performing some useful work in return for which other people give us food, with or without money exchange—urban culture.

These three forms have usually followed one another in successive stages of cultural evolution. The change from food gathering to direct food production was in each case an economic revolution, the importance of which would be difficult to exaggerate. In fact, the rise of material civilization has been made possible by the discovery of and advances in food production in agriculture and stock-breeding, accelerated by the division of labour to permit their industrial exploitation.

It is impossible, of course, to discuss in detail the fascinating story of man's attempts to conquer his environment. We must be impressed with the slowness of his development. We must also be impressed with the fact that man owes his development to the fact that he could and did influence his environment. The myth that primitive man was in complete harmony with his environment has been shattered (Biswell (3), Childe (5, 7), Clarke (9, 10), De Morgan (15), Elliott (18), Guiraud (20), Malin (33), Nietsch (35), Sauer (39), Toutain (46)—to quote a few).

We may start with the Natufians—so-called after one of the valleys near Mount Carmel in Palestine—in whose caves were discovered the first flint sickles. Here we have very early evidence of man's interest in cereal grasses. Theirs was an economy of food gatherers. No grains were sown. They had no pottery, no ground stone axes, and no domestic animals. Their interest in the latter is shown, however, in the bone handles adorned with carving of animal's heads. The period was probably not later than 6000 B.C. It was a Mesolithic (middle stone-age) culture.

The Sialk settlements on the Iranian plateau were of the same period. In addition to sickles they also had saddle-querns for grinding grain.

Early steps in cultivation have been inferred from some settlements in Egypt: the Tasians, a semi-nomadic people on the east bank of the Nile in middle Egypt; the Fayums, who lived in settled groups on the edge of a lake that filled the Fayum depression, and who provide us with early definite evidence of the cultivation of emmer wheat and barley and of keeping domestic animals; and the Merimdians, very like the Fayums, who dwelt on the west edge of the Nile delta. Here were definite Neolithic cultures, estimated mainly on geologic grounds to have existed between 6000 and 5000 B.C.

Later came the period of the spread of the great Danubian cultures over central Europe from the Drave to the Baltic and from the Vistula to the Meuse, "on loess lands, not too heavily wooded" according to Childe (5), who wrote (7): "For the greater part of the time they were engaged in adapting their economy and their equipment to a strictly specialized and localized environment. The latter would offer each society its own distinct opportunities

for discoveries and inventions. So each group would develop peculiar traditions appropriate to its own circumstances. This is just what archaeology and ethnography reveal".

Agriculture was now the basis of life and hunting was less important. Probably at this time the Egyptian calendar was introduced as a means of foretelling the date of the annual flooding of the Nile—an event of greatest importance for the Egyptian farmer. The first hoe was used to break up the ground for crops, which were harvested, as before, with flint sickles. The appearance of the plough, about 3000 B.C., was an important landmark in the history of the agricultural economy.

Man had discovered that if he let the brush grow over his deserted plots and then burned down the scrub he could again reap good crops (Childe (6)). He found that if he grazed stock on cleared lands the droppings of the flocks and herds restored fertility to the soil, making new crops possible.

Intensification of animal husbandry is attested about 3000 B.C. by the tribal territory of Lagash, a Sumerian city of probably 36,000 adult males. Livestock included a stud bull imported from Elam (where, according to Elliott (18) the wild ox was first domesticated 5000 years earlier), since it was thought that stock was likely to deteriorate on the sultry plains if not crossed periodically with mountain breeds.

Guiraud (20) records that during the Hellenic period the plough was not improved, wheat and barley were still mown with the sickle, and the grain was still threshed by trampling of oxen or mules.

Also discussing the Greeks, Toutain (46) writes: "They saw the imperative need of submitting themselves to nature, but they also corrected nature as far as it was possible. They terraced steep slopes. They made damp, unhealthy plains wholesome by skilful drainage-works, and led water to dry land by irrigation channels. They cleared ground of stones. They altered and improved the quality of certain lands by mixing in other soils in a manner which M. Guiraud compares to the operations which we call marling, liming, or manuring with plaster".

"An attempt was made to determine what sort of manure suited each crop," Toutain goes on to say. "They also knew that the straw, grass, and vegetable debris left over from certain operations enriched the soil, and that wood-ash, when mixed into the soil of an exhausted piece of land, gave it a little fertility." They practised an elementary form of crop rotation: vegetables and cereals in turn.

Discussing agriculture in the Iron Age, Childe (7) describes the migration overseas and the development of specialized farming, which broke down the routines of agriculture and made experimentation compulsory. "A Phoenician or a Greek, transplanted to Italy or North Africa, could hardly help noticing the effects of the new soils and climates upon the seeds, cuttings, and young animals he took with him. Experience showed that a vine-stock from Lebanon produced different grapes on the slopes of Vesuvius or the plains of the Rhone Valley. Moreover, new plants and animals were introduced, as well as new methods, as part of the general diffusion of peoples; thus the Persians introduced alfalfa into the Mediterranean, probably, when they invaded Greece in 490 B.C. They themselves learned to cultivate rice after their conquest of India".

The revolving mill for grinding grains first appeared in the Mediterranean world in the fifth century B.C., invented by some forgotten forerunner of Archimedes—a brilliant engineer or mathematician. Three centuries later portable revolving mills were used by the Grecian and Roman armies. About 100 B.C. the vertical water mill made its appearance and 1100 years later no fewer than 5624 were listed in the Domesday Book. The windmill is thought to have appeared between the seventh and tenth centuries B.C. in Persia.

The tractor plough was a rather natural development from the animal-drawn plough and from the hoe. In contrast to this, the harvesting machine is in no way connected with the sickle or scythe. It is a product of the machine age. And this illustrates the truth that in a peasant culture, implements undergo a gradual and progressive evolution, each stage of improvement being such as could have been

effected by an illiterate peasant. On the other hand, in a culture such as ours today, based on industrial food production, conservatism is swept away. Improvements are made—often of the most radical kind—not by farm labourers, but by men especially trained for the purpose. Such improvements are apt to be revolutionary and do not necessarily develop naturally out of pre-existing implements and methods.

The first animals domesticated for their food value were those we still use for the same purpose: cattle, sheep, goats and pigs. It is striking that the earliest domestication of animals as a means of controlling food supply seems to have taken place at about the same time as the earliest cultivation of cereals.

Some tribes became herdsmen, accompanying the flocks and herds in the animals' annual migrations, protecting them from predators, and gradually increasing control over them. Thus the herdsmen were nomadic, in contrast to the tribes that depended primarily on domesticated plants.

The consequences of this division of agriculture have extended, as we shall see, down to the present day. Hatt (23) has charted this division of labour in man's cultural evolution.

In parts of Europe where geographical features admit, a modified form of nomadism called transhumance has survived. This involves the annual migration of villagers from their homes to the upland ranges, with their herds, to spend the summer months. In Norway, Switzerland, the Balkans, Italy and Spain this annual migration to summer pastures is a well-known feature, the herders living a simple life in wooden huts built among the mountains, milking the cattle and making cheeses. This is also still the practice in parts of Turkey (Harlan (21)) and Spain. We can see a modification of transhumance in our high summer mountain grazing in the western United States. The grazing animal has been continually pushed back to less productive land as man has learned how to use areas for more intensive agriculture.

Let us now review what must have been involved in the domestication of plants. Early man took wild plants, or their fruits and seeds, from their natural environments and provided different environments nearer home. Or he attempted to modify conditions of the environment where the plants were growing wild. Differences in climate were very effective in limiting the distribution of some plants, but not others. Some soils were infertile. Certain plants thrived on a variety of soils, whereas some plants thrived on one soil only. Some crops were easier to harvest than others. Certainly there were many limiting factors to overcome.

But what we are interested in is the fact that, in spite of ignorance, superstition and untold difficulties, man gradually developed an efficient agriculture. As he gained experience in animal and field husbandry he became increasingly aware of the fact that he was dealing with the inter-relations of a climate/soil/plant/harvest complex (Love and Williams (31)).

Let us look at a cross-section of agricultural crops. Compare the natural vegetation found in the desert with a date-palm plantation there. To grow date palms successfully in the Southern California desert, for example, man had to learn to overcome the limitations of lack of water, infertile soil, and, particularly, difficulties of harvesting.

Think of the bunchgrass association that once existed in the Sacramento Valley of California, and compare it with a highly productive rice field. A great deal had to be learned about the limitations of nature and how to overcome them by the controlled use of water, proper fertilization, improved plant varieties, and specialized harvesting equipment. All the problems are not yet solved, of course, but new helpful techniques are continually being brought to light by constant research.

There are now thousands of acres of irrigated pastures in the arid regions of the world. This has been made possible through the use of improved varieties of grasses and legumes, improved soil fertility, water control, and regulated livestock grazing—all developments that have overcome nature's limitations.

Millions of acres of dryland pastures now exist on what was once relatively, if not absolutely, unproductive range and wild land. For example, there are more than 11 million

acres of highly productive subterranean clover pasture in the "well watered"—15 in. or more annual rainfall—region of southern Australia alone (Love (30)). Phosphate and clover have done wonders to some of New Zealand's rough range country. But on most of the range and wild lands, livestock must still search for forage as Mesolithic man searched for food.

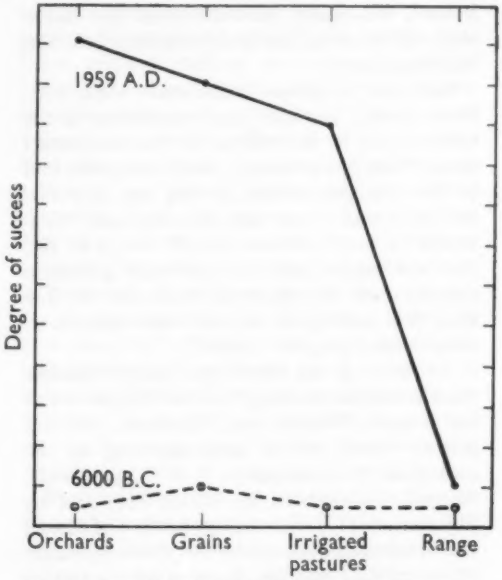

Fig. 1. Crop diversity and degree of success in overcoming limitations imposed by climate, soil, pests, plant variety, and harvesting difficulties.

Fig. 1 is an attempt to illustrate the diversity of agriculture and man's degree of success in overcoming the limitations of nature in order to raise and harvest the desired crop. There was considerable variation in the degree of success in learning to handle the many and diverse crops. Indeed, that degree of success varies from crop to crop even today, as we very well know. But gradually, over the last 6000 years, man has progressed with many crops. Ten thousand years ago he roamed about collecting the fruits and nuts of trees and shrubs and vines, and the seed of grasses. Now he has orchards and vineyards, and fields of improved varieties of wheat, oats, and barley. His animals used to forage in the hills for existence. Now, in favoured places, they too profit from man's intensive agriculture—irrigated pastures, corn, sorghums, alfalfa, hay, silage and the like. But on the range and wild lands of the world today there has been little change in the past thousands of years.

We might define agriculture as man's attempts to overcome the limitations of nature in order to raise and harvest the desired crop. We can safely say that the degree of success in overcoming these limitations is almost directly proportional to the effort expended in growing and harvesting the crop. And this applies to research as well as to practical husbandry. Rangeland husbandry—the harvesting of the grassland crop by animals—must be regarded as a phase of agriculture if we are to make any progress in our last agricultural frontier. The difference between range and other forms of agriculture is entirely one of degree. There is nothing unique about land use by the grazing animal that sets it apart from other forms of agricultural use.

Our task is to raise the last point on the curve. But, for the moment, I want to ask where you can break the line and say "on the left is agriculture and on the right is something else". Fundamentally, all points have this in common: in any climate on any soil a crop is being grown (whether planted or not) and harvested. Range management suffers in comparison with that of other crops in at least three ways: research is many years behind, there is a smaller degree of success in overcoming the limitations of nature, and there is too often an unwillingness among both scientists and farmers to do anything about it.

There seems to be wide agreement that primitive man domesticated animals and developed his cultures in or near forested or wooded areas (Childe (5), Clarke (9), Curwen (13)). Bailey (1) quotes D. W. Prowse: "All wild sheep were mountain and highland animals". Elliott (19) wrote that the wild ox was domesticated in Elam, in the mountains of eastern Babylonia, about 8000 B.C. On the origin of domesticated cattle Bailey (1) quotes F. B. Mumford: "*Bos primigenius* (urus) existed down to historic times in the forests of

Europe". The natural vegetation around ancient Natufia was broadleaf evergreen forest (mostly oaks) and shrub forms (Küchler (25)). This is confirmed by Boyko (4). Nietsch (35) wrote lyrically: "Where the oak trees grow best, there they find the best fields, there their cattle prosper, and they bide themselves as energetic and doughty peasants of the woodland . . ." (translation by Clarke (9)). Schütrumpf (40) stated that a steppe flora flourished only until overtaken by the forests advancing into the zone vacated by the ice sheets. The earliest farming communities did not penetrate Europe until the recolonization of the forests was well advanced. Paleobotanical evidence points to Neolithic settlements as the cause for the appearance of grasses and plants other than forest trees. Tansley (44) affirms the same for the British Isles. Pollen analysis in northern Europe has shown with great precision the succession: birches and willows, then pines, then hazel, soon elms, limes and oaks—the mixed oak woods, and finally the beech (Childe (5)). This has been more recently reviewed by Darby (14). The loess soils carried an oak-mixed forest with hazel undergrowth (Clarke (9)). Smiley (42) has concluded that in the southwestern United States the Navajo "have lived generally on the fringes of the pinyon (*Pinus edulis*) forests".

In view of the foregoing evidence, Hartley and Williams' (22) conclusions concerning the origins of grass species now in commercial production are of considerable interest. They point out that few, if any, of the important cultivated grasses are constituents of the flora of the major grasslands of the world. Ecologically, the typical meadow grasses of Europe (*Poa*, *Festuca*, *Lolium*, and *Dactylis*) are allied to, and probably derived from, woodland and forest margin types. Hartley and Williams think that if there was a significant evolutionary development of grass species and grazing animals during the same period—late Pliocene and Pleistocene—this may have led to grasses especially adapted to grazing. If, as seems to be the case, the domestication of animals occurred in the same regions, then the predecessors of the meadow grasses would have been subjected to even more intensive grazing pressures in the communities occupied by Neolithic man as he colonized Europe.

Primitive man felled and burned trees, and cultivated the cleared ground; the grasslands of Europe were largely the result of human activity. When the ground had been cleared, the soft leaf mold of the clearing could have been loosened easily by crude flint hoes. Indeed, European pioneers used the same methods in the agricultural conquest of eastern North America.

But, was it a new experience when men from western Europe found themselves in the treeless area in the middle of this continent? Since, throughout history, such men have had to clear an area before grazing was possible, and here was a vast area already clear, what would be more natural than for them to feel that the *status quo* (the so-called grassland climax) must be preserved? Was this the first time that ecological studies were conducted on extensive grassland areas?

As far as I can determine, range management concepts developed in the United States are unique. Weaver and Clements (48) did pioneer work on an understanding of the ecological relationships of grasslands. Sampson is credited by Parker (36) and by Dyksterhuis (17) with the application of climax and succession concepts to range management. However that may be, range research and its application have been approached primarily from the ecological standpoint. This is understandable, since it was a natural development from early studies of botanists chiefly interested in the floristics of grassland vegetation. Much of the ecological research has been devoted to the determination of climax vegetation which is described as "normal" vegetation, undisturbed by man or man's activities. It is said to be a natural vegetation which has completed development to a condition of relative balance.

There can be no quarrel with the aims of the ecologists to determine what the climax might have been. The more pure research we have, the better. But, unfortunately, climax vegetation has been used as a basis of comparison for evaluating range condition.

In a standard textbook on range management the authors admit that "determining climax or normal conditions is difficult and sometimes almost impossible" (Stoddart and Smith (43)). But they go on to state that "protected areas, conservatively grazed ranges, ungrazed fence corners or cemeteries, and such indicator areas must be sought out and studied carefully. Certainly it is unwise to outline management objectives before the site potential is well understood". They state that "this method, despite its faults, is rapidly becoming the most used basis for deciding on stocking intensity in America". What is more remarkable is that this leads them to conclude that "this attests to its general soundness and reliability compared with other methods". Actually, it is the most used method in America because it is used by the federal agencies that administer the grazing of so much federal land. In spite of the current situation, the livestock people "look forward hopefully to a time when scientific study and conclusion will guide National Forest policy, instead of arbitrary decree from an, at present, all-powerful bureaucracy. Thus and thus only will the widest measure of multiple use of our National Forests be achieved" (Lee (27)).

Parker (36) stated that the concepts of plant succession, particularly as induced by grazing use, have been especially useful to the range manager. As I have indicated, he credits Sampson (38) with recognizing "that the standards of range-condition classifications must have a firm ecological basis, wherein each condition class corresponds to a stage or group of stages in secondary succession".

Dyksterhuis (17) still asserts that range management principles must be referred to the natural vegetation: "Uncultivated range lands long protected from grazing and with relatively stable vegetation are used to determine practical subdivisions and suitable names for the units of the ecosystem. In developing this classification of abstract units we may still say with Clements (11): 'The natural plant communities are not merely the best integrators of the effects of climate and soil, but axiomatically they are also by far the best judges of these two complexes in terms of plant production'. The units of the physical environment that are mappable and that also subtend a significant difference in kind or amount of climax vegetation are termed 'range sites'".

To Dyksterhuis (17) "*range land* means land on which the climax vegetation is a natural pasture". And here is the major conflict. I agree with Constance (12) and many others that it appears questionable how much "natural vegetation" is left anywhere in the world. Constance (*loc. cit.*) went on to say: "Our childhood faith in the quasi-universality and comforting stability of the so-called climax-communities has been rudely shaken if not irretrievably shattered". In fact—and this is my thesis—the domestic animal has as great or greater an impact on the "natural vegetation" as the plough. Intensive agriculture disturbs the plant community. So does the grazing animal. The range, therefore, is no longer a climax but a modified ecosystem.

The procedure of evaluating range condition in terms of climax vegetation implies a number of assumptions: first, that it is possible to determine climax; second, that climax vegetation is the most productive; third, that it is possible to have climax vegetation in the presence of domestic animals, or even wild life, subject to man's hunting and preservation laws; fourth, that any departure from climax is retrogression—a downward trend; and any improvement in range condition can only be brought about by reduction of livestock (Tussock Grassland Research Committee (47)).

It is incredible that it appears necessary to point out the fallacies in these assumptions. Harlan (21), writing of Turkey's range and livestock problems, said succinctly: "The Turkish needs are for more forage rather than for fewer livestock". The same is increasingly true of the western range in the United States.

The climax concept has been severely criticized by a number of scientists as well as by the historian Malin. I have recently discussed this rather fully (Love (29)) quoting such eminent men as Constance (12), Egler (18), and Christian and Donald (8). Egler's

opinion is summed up as follows: "Contrary to the history of many firmly grounded sciences, we do not find in ecology a clear-cut understanding of the problem to be investigated . . . We do not find hypotheses proposed, concepts suggested, theories established, all retained *as* hypotheses, concepts, theories and their statuses altered as soon as conflicting data demanded a reconsideration. Instead, we find . . . a brilliant and elaborate superstructure raised not as hypothesis but as 'established fact'".

Malin (33) states that "the conventional or traditional concept of the state of nature must be abandoned—that mythical, idealized condition, in which natural forces, biological and physical, were supposed to exist in a state of virtual equilibrium, undisturbed by man (climax in our terms). The role of aboriginal man within the ecosystem must be recognized as a major ecological fact". The true state of nature existed only prior to the emergence of man, and this was at least as long ago as before the last Ice Age (Childe (6)). When primitive man appeared on the scene he modified such a state because he possessed the unique capacity to act with a purpose. No matter how primitive, man introduced the factor of planning with an element of choice (see also Thomas (45), and Biswell (3)). Speaking of American grasslands, Malin (32) recognizes three stages: the first deals with the true state of nature, the second with the influence of aboriginal man, and the third with modification by European man. One may ask whether you want pleistocene, miocene, pre- or post-aboriginal "climax" vegetation.

Perhaps even more serious, "whenever and wherever a discussion is proposed of man-earth relations, or of man-food relations, certain fundamental conceptual barriers usually tend to block a free and effectual meeting of minds about even the nature of the problem. One of these is the assumption, tacit or explicit, that, as differentiated from plants and other animals, man's relations with the earth and all its properties are always destructive. A second barrier, which is really a corollary of the first, is that the imperative responsibility of any student of these matters is to provide the bases for restoring what man, especially 'civilized' man, has supposedly destroyed" (Malin (34)). He points out that a natural resource is not determined by the properties of the earth *per se*, but by the qualities of the minds of men. This is, of course, obvious with such resources as coal, uranium, or oil, but it applies equally well to ranges, wild lands, and watersheds. In other words, the range resource is not of full value to man unless and until he learns how to get more out of it.

This brief review of "origins, causes, principles" mentioned by Curwen certainly supports Berrill's belief that none of our answers is truly final. Once more, a question that seemed to have been settled is again thrown open to inquiry.

Riney (37) has pointed out that research workers are better able to plan their research if the proposed land use is kept clearly in mind. This is not easy to do with rangeland, because much of the wild land containing range areas is managed by one or another of the federal services on a multiple-use basis: watershed, timber, mining, recreation and grazing. A further complication is that industrial development and intensive agriculture are making increasing demands on our water supplies. In an area of man's activities that involves research people with so many different interests and backgrounds, it is urgent that the agricultural scientist participate. We must not divorce agricultural research from that of our ranges and wild lands.

Compare, for example, the climax/relict area/site potential concept with the statement of Love and Williams (31): "The most feasible way of assessing manipulations of the range complex is to compare them with non-manipulated range. For instance, on two soil types in California, seeded *Trifolium* species produced over three times the forage and six times the protein when phosphated, compared with untreated land. It seemed inappropriate to estimate range or site 'potential' based on an estimated climax vegetation that had not been present for 100 years before putting into practice the results obtained from manipulation experiments. By appropriate

manipulations of soil, plants, and animals, restrictions imposed on range vegetation by soil and climate can be modified so that entirely new horizons may be attained. Climax vegetation need no longer be the ultimate goal in range improvement any more than it is in other phases of agricultural production."

One of the striking features of pasture development in southern Australia is the lack of relationship between the climax communities and sown *Trifolium* pastures. They have been established successfully on areas that formerly supported at least six different climax communities varying from wet sclerophyll forest to dry heath. The environment created by man with the use of fertilizer, the introduction of species, and the intensification of management has overcome the limitations of nature and superseded the pattern of native vegetation (Christian and Donald (8)). This should not be surprising, since the same thing has been done in every region of the world where man has established a successful agriculture.

It is difficult for me to understand the fact that in countries where man has done so much to develop a successful intensive agriculture, he is not only content to use the natural vegetation for rangeland, but also believes the range must be maintained in its natural state, whether it be the range country of the United States, the pastoral areas of Australia, the high country of New Zealand or the pastizales of Spain. Hormay (24) has given us an example of what can be done on the roughest range country. And there are other examples (Love 28)).

Farming is perhaps the "science and art" most comparable to the "science and art" of grazing and wild-land management. Both involve a complex of factors inherent in climate, soil, plants and harvesting. Man has associated agriculture with the plough ever since the tool was invented—about 3000 B.C. But, certainly, recent advances in the use of fungicides, insecticides, rodenticides, herbicides, fertilizers, irrigation practices, harvesting equipment and methods, have shown that the plough is not necessarily the most important implement on the farm. In addition to using improved varieties of crops, the farmer modifies the environment by improving soil fertility, encouraging the crop and discouraging the weeds, and improving his harvesting methods. He may do one or all of these things. Note how the orchardist has progressed in 8000 years (Fig. 1). As with range and wild land, the problems are basically of an ecological and physiological nature, but they have not been solved by traditional ecological research methods.

Grassland, whether natural or artificial, is a renewable resource. Facing the grassland research worker is the problem of developing research programmes that will ensure the continuity, improvement and more efficient utilization of this resource. Stated in its simplest terms, we lack precise information on the responses of species to manipulations of the environment. Here we can profit from what has been done in other phases of agriculture. The plant physiologist, for example, develops herbicides that kill the weeds and leave the crop. This is possible because he has determined the *differential* response of the species to the herbicide. In a like manner, we must determine the differential responses of range species, desirable and undesirable, woody and herbaceous, to environmental manipulations such as differences in fertility levels and clipping and grazing treatments (Hormay (24), Laude *et al.*, (26)). Before that can be accomplished we must develop information on the nutrient requirements of our range species. Then, when the differential responses are known, it should be possible to develop chemical tests for the nutrients required in different soils, so that with the use of appropriate fertilizers, a better grassland crop can be grown. Implicit in the above, but important enough to warrant special attention, is our lack of knowledge of the interactions of nutrients (including micronutrients) on microflora/legume relationships. New Zealand and Australian workers have shown us the importance of legumes in building up permanent soil fertility. Griffiths Davies (15) wrote: "Enormous tracts of country underdeveloped because of low soil fertility can be unlocked by the correction of soil mineral

deficiencies, allowing the establishment of leguminous pastures and the build-up of soil nitrogen . . . Our past concepts of developmental possibilities must be drastically revised."

I would like to sum up what I have been trying to say. The range crop is a complex of species. Animals harvest the range crop, whereas machinery generally does the harvesting in intensive agriculture. Thus we are confronted with a climate/soil/plant/animal complex. But we must stop divorcing agriculture and improved dryland pastures from range in our thinking about the potential of our ranges and wild lands. Manipulation of soil fertility by the proper application of needed nutrients increases forage production, lengthens the grazing period and improves the nutrient content of the feed. The introduction of better adapted species (especially legumes), where feasible, improves forage production and quality and frequently permits the economical utilization of higher levels of soil productivity made possible by fertilization. Management of grazing time and intensity is an important aspect of the complex, but must be considered even where fertilizing and seeding are still uneconomical.

In the last quarter of a century a great deal has been learned about improving potential production on our rangelands, and the climax vegetation (even if we could define it) need no longer be the goal in range and wild-land management any more than it is with other crops. If we are to realize this vast potential of our ranges, we must be willing to do as other scientists have done. Classical ecological principles must be critically evaluated in the light of current research findings in allied sciences. If this be done, we can enter a new era in the development of ranges and wild lands here on earth, just as the physical scientists are now probing worlds once thought beyond the limits of man's domain.

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THE EFFECT OF URINE AND ITS COMPONENTS ON THE BOTANICAL COMPOSITION AND PRODUCTION OF A GRASS/CLOVER SWARD

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A study was made of the effect of sheep urine and some of its components on herbage production. The return of urine to the sward increased production from the grass species; the clover content of the sward was reduced.

The application of nitrogen or potassium fertilizer equivalent to the normal return of nitrogen and potassium in urine increased production, but not as much as urine. The return of nitrogen and potassium fertilizer together increased production and altered botanical composition in much the same way as did urine.

On a grass-dominant urine-treated sward the application of nitrogen fertilizer increased the "efficiency" of urine.

The effect of urine on a grass/clover sward was almost entirely due to its nitrogen and potassium content. The water and indole acetic acid content of urine had no effect on pasture production or composition.

INTRODUCTION

A large proportion of plant nutrients removed by the grazing animal is returned to the pasture in dung and urine. The value of excreta was shown by Davies (3). More recently a series of studies on the effect of sheep urine and dung on the pasture has been conducted in New Zealand by Sears and his colleagues (7, 8, 9) and in this country by Watkin (12, 13) and Wheeler (14,15).

The New Zealand workers found that the clover content of the pasture was reduced by urine (9), a result which was confirmed by Watkin (13) and Wheeler (14). Sears and Goodall (8) reported increases in pasture production of 15% due to return of urine. Watkin (12), on the other hand, found that, in the absence of nitrogen fertilizer, urine reduced pasture yield. This response was explained as being due to the depressive effect of urine on clover and the consequent loss of clover nitrogen. On a sward receiving 3 cwt. or more nitro-chalk per acre, urine increased production. It was suggested that the effect of urine on the pasture could not altogether be explained in terms of its nitrogen and potassium content (13), and might in part be due to the auxin- and water-content of the urine.

The auxin content of sheep urine is of the order of 4–5 mg./litre, probably in the form of indole acetic acid or with heterauxin base, and has some effect on plant species (5).

Urine contains 70% of the total nitrogen and nearly all the potassium excreted by the animal. Nitrogen excreted in urine was measured by Doak (4) as equivalent to a spot dressing of 400 lb. N/acre. This has a considerable temporary effect on soil pH and $(NH_4)^+$ and $(NO_3)^-$ ion concentration (10, 11), which kills off some clover and, to a lesser extent, grass seedlings, in the area.

The experiment discussed in this paper was designed to investigate the effect of urine and some of its components on a grass/clover sward under field conditions.

METHOD

Materials and procedure

The experiment was conducted over the two years 1954–5. The experimental area was sown in 1950 to a mixture comprising ryegrass, cocksfoot, red and white clover. By early 1954 the sward had become a ryegrass/white clover

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association with a little cocksfoot. In each year the experiment was grazed 8 times between May and mid-October at the 4–6 in. stage by wether sheep. The sheep were harnessed with bags to collect all dung and urine (see Watkin (12)).

The components of urine considered in the experiment were nitrogen, potassium, water and indole acetic acid. After each grazing the urine collected was analysed for each of these. The amount of each that would have been returned in the urine to each treatment was calculated for each grazing. The figures given by Watkin and Wheeler for the amount of urine produced per lb. of dry matter consumed for this pasture were used in the calculation (see Table 1).

TABLE 1. Production of urine in lb. per lb. D.M. eaten (ryegrass/white clover sward)

	Spring	Summer	Autumn	Reference
1954	2·4	2·2	2·3	Watkin (13)
1955	2·3	2·1	2·5	Watkin, revised Wheeler (14)

Treatments and layout

The urine treatments were as follows: (a) nil, (b) water, (c) urine.

These treatments were combined with the nitrogen, potassium and indole acetic acid factors in a factorial design as follows:

1. Nitrogen: (a) nil, (b) nitro-chalk, (c) urea.
2. Potassium: (a) nil, (b) potassium sulphate.
3. Indole acetic acid: (a) nil, (b) indole acetic acid, horticultural grade.

The factorial layout of $3\times3\times2\times2$ was replicated twice. Plot size was $12\times4{\cdot}5$ ft.

Measurement of productivity

A strip 1 ft. wide was cut down the length of each plot with an adapted Tarpen Trimmer hedge cutter before each grazing. Grazing by wether sheep to the level of the sample strip was usually completed overnight. Dry-matter determinations were made on all samples.

Calculations

Calculations of the amounts of each factor to be returned to each treatment after grazing were made on the basis of the proportional return technique of Sears (7). The product of the dry matter per plot and the weight of urine produced per lb. of dry matter gives the weight of urine for each plot. The product of this figure and the weight of nitrogen (or potassium or indole acetic acid) in 1 lb. urine gives the amount of nitrogen (or other factors) which would be returned in the urine. The amount of

TABLE 2 (a). Return of nitrogen and potassium in fertilizer lb./acre

	1954				1955			
	Nil		Urine		Nil		Urine	
Treatment	N lb.	K lb.	N lb.	K lb.	N lb.	K lb.	N lb.	K lb.
Nil	—	—	—	—	—	—	—	—
Nitro-chalk	86	—	122	—	106	—	205	—
Urea	87	—	112	—	94	—	186	—
Potassium sulphate	—	85	—	133	—	72	—	101
Nitro-chalk and potassium sulphate	106	105	124	122	121	100	172	155
Urea and potassium sulphate	101	99	121	118	113	91	180	144

TABLE 2 (b). Return of urine and of nitrogen and potassium in urine per acre

	1954			1955		
Treatment	gal.	N lb.	K lb.	gal.	N lb.	K lb.
Urine	1123	107	101	959	108	87
Urine and nitro-chalk	1463	122	123	1887	205	170
Urine and urea	1422	112	115	1530	124	149
Urine and potassium sulphate	1367	119	113	1010	124	101
Urine, nitro-chalk and potassium sulphate	1520	124	122	1666	172	155
Urine, urea and potassium sulphate	1460	121	118	1529	180	144

TABLE 2 (c). Urine analysis

1954				1955			
Date	S.G.	N%	K%	Date	S.G.	N%	K%
23/3	1·034	1·70	0·93	14/4	1·040	1·01	1·08
23/4	1·033	1·14	0·99	9/5	1·035	1·15	0·66
26/5	1·042	1·46	1·25	2/6	1·038	1·23	0·93
23/6	1·033	0·84	0·76	21/6	1·029	0·81	0·62
16/7	1·033	0·74	1·00	5/7	1·048	1·45	1·56
18/8	1·023	0·49	0·98	15/8	1·043	1·58	1·13
15/9	1·023	0·94	0·61	16/9	1·043	0·94	0·59
13/10	1·025	0·69	0·63	17/10	1·024	0·92	0·59

nitro-chalk, urea or potassium sulphate to be applied to the plot is then calculated. Hence each treatment received the amount of the factor concerned that would have been returned in urine had the urine not been collected.

The amount of nitrogen and potassium returned in the fertilizer and in the urine is given in Table 2a and b; urine analysis is given in Table 2c.

Method of application of urine and fertilizer

Application of urine and fertilizer was made within 36 hours of completion of each grazing. The urine was returned to the appropriate plots by splashing it out of a container, to give patches similar to that which would have been made by the grazing animal. Only on highly productive pastures is urine comparatively evenly distributed. The fertilizer was roughly broadcast over the appropriate plots, simulating to some extent the uneven distribution of urine patches. Superphosphate was applied to the experimental area at the rate of 5 cwt. per acre per year.

Botanical analysis

The percentage productivity method described by Wheeler (15) was used. Five throws of a 6×6 in. quadrat were made on each plot. Since the water and indole acetic acid treatments had no appreciable effect on botanical composition or herbage production these results are omitted in order to simplify presentation (Mundy (6)).

Botanical composition

The effect of the treatments on percentage of clover in the sward is shown in Table 3.

The clover content of the sward was higher in 1954 than in 1955, and it is suggested that this difference is largely due to the dry summer of 1955 being detrimental to clover production (15).

The application of nitrogen fertilizer reduced both the percentage of clover in the sward and also the clover production. The application of potassium sulphate, whilst reducing the percentage of clover through increased grass production, also increased clover production. With nitrogen fertilizer the effect of the application of potassium sulphate was to maintain clover production. Both nitrogen and potassium increased grass production.

Urine behaved in a similar manner to the combined application of nitrogen and potassium fertilizer in 1954. However, on the grass-dominant sward of 1955 urine reduced

TABLE 3. Botanical composition

Clover production lb./acre and clover as % of grass and clover

	1954				1955			
	Nil		Urine		Nil		Urine	
Treatments	Clover %	Clover production lb./acre	Clover %	Clover production lb./acre	Clover %	Clover production lb./acre	Clover %	Clover production lb./acre
Nil	67	2400	52	2300	42	1200	16	700
Nitro-chalk	46	1900	29	1800	15	600	4	300
Urea	46	2000	38	2500	18	700	4	300
Potassium sulphate	60	2800	53	3300	38	1300	20	900
Nitro-chalk and potassium sulphate	47	2500	32	2100	22	1100	5	400
Urea and potassium sulphate	54	2800	38	2400	24	1100	7	600

TABLE 4. Production of herbage dry matter in lb. per acre

Treatment	1954 Nil	1954 Urine	1954 Mean	1955 Nil	1955 Urine	1955 Mean
Nil	3600	5300	4400	2800	4600	3700
Nitro-chalk	4100	6300	5200	4300	8300	6300
Urea	4300	6500	5400	3800	7100	5500
Potassium sulphate	4600	6200	5400	3500	4700	4100
Nitro-chalk and potassium sulphate	5300	6700	6000	5100	7700	6400
Urea and potassium sulphate	5200	6400	5800	4500	8000	6300
Mean	4500	6200	5400	4000	6700	5400

Significance: *1954:* Urine***, nitro-chalk***, urea***, potassium sulphate***. Least significant difference between individuals = 700 lb. ($P = 0.05$). Coefficient of variation 7·2%.

Significance: *1955:* Urine***, nitro-chalk***, urea***, potassium sulphate***. Urine × nitro-chalk***, Urine × urea***, Urine × potassium sulphate***. Least significant difference between individuals = 600 lb. ($P = 0.05$). Coefficient of variation 5·1%.

clover production. In both years the application of urine to a sward receiving nitrogen and potassium fertilizer reduced clover production and increased grass production.

Pasture production

Herbage yields are given in Table 4. In both years the application of urine, nitrogen fertilizer and potassium fertilizer individually and together significantly increased pasture production ($p < 0.001$).

In absence of other treatments the increase in production in 1955 due to the application of a total of 106 lb. N/acre as nitro-chalk was 16·3 lb. D.M. per 1 lb. nitrogen in spring, 10·1 lb. D.M. per 1 lb. N in summer and 9·8 lb. D.M. per 1 lb. N in autumn. The corresponding figures for production increase due to the application of a total of 94 lb. N/acre as urea were 11·4, 8·5 and 8·6 lb. D.M., respectively. In 1954 the same seasonal trend was observed, but unit response was smaller, owing to the higher production of the control and the higher level of clover in the sward. Nitro-chalk was superior to urea in 1955, but in 1954 urea gave slightly higher yields.

The application of potassium sulphate (85 lb. K/acre in 1954, 72 lb. K/acre in 1955) significantly increased herbage production. The soil had previously been classed as low in potash, so a yield response to potassium sulphate was likely. In 1954 40% of this increased production was due to increased clover production; however in 1955, when the clover content of the sward was smaller, clover made up only 14% of the increased production.

In the autumn of 1954 and throughout 1955 the application of potassium sulphate to urine-treated plots did not increase production.

Statistical analysis of dry-matter production figures demonstrated an interaction between the urine and nitrogen treatments significant in 1955 ($p < 0.001$) but not significant in 1954.

Because of the proportional return technique used, the absence of a positive interaction may indicate a falling-off in response to urine or nitrogen. Table 5 shows this effect for 1954, the response to fertilizer nitrogen being

TABLE 5. Urine and nitrogen interaction

Treatment	1954 Yield, lb. dry matter per acre: Nil	1954 Yield, lb. dry matter per acre: Urine	1954 Increase per lb. N in urine	1955 Yield, lb. dry matter per acre: Nil	1955 Yield, lb. dry matter per acre: Urine	1955 Increase per lb. N in urine
Nil	4400	5700	12·0	3300	4500	10·0
Nitro-chalk	4900	6100	10·0	4600	7700	16·6
Urea	4800	6100	10·5	4200	7100	14·2

Response to fertilizer nitrogen is considered uniform.
Significance, 1955 only: nitro-chalk × urine***, urea × urine***.

TABLE 6. Comparison between urine and nitrogen and potassium treatments

1954	Nil	Potassium sulphate	Nitro-chalk	Urea	Nitro-chalk and potassium sulphate	Urea and potassium sulphate	Urine
lb. N/acre returned	—	—	86	87	106	101	107
lb. K/acre returned	—	85	—	—	105	99	101
Yield lb. D.M./acre	3560	4620	4130	4390	5340	5160	5290
Increase in yield per lb. N	—	—	6·6	9·5	16·7	15·8	16·1
Yield difference between individuals for significance (P =0·05) 750							
1955							
lb. N/acre returned	—	—	106	94	121	113	108
lb. K/acre returned	—	72	—	—	100	91	87
Yield lb. D.M./acre	2800	3450	4250	3810	5120	4460	4560
Increase in yield per lb. N	—	—	13·7	10·7	19·1	14·7	16·2

Yield difference between individuals for significance (P =0·05) 570. Where treatments have received potassium no allowance has been made.

considered uniform. The total amount of nitrogen, both fertilizer and in urine, on the urine/nitrogen fertilizer plot is greater than the sum of nitrogen returned to the individual nitrogen fertilizer and urine plots.

A comparison of the application of urine alone with the nitrogen and potassium fertilizer treatment shows a close similarity with regard to production, as shown in Table 6. In 1954 the difference in production between these treatments is very small in comparison with yields. In 1955 the urea/potassium plot was again similar to the urine, but the nitro-chalk/potassium plot gave a significantly higher yield.

DISCUSSION

Yield differences between urine and any factor or combination of factors become exaggerated when the proportional return technique is used, owing to the unequal quantities of nitrogen and potassium applied in the fertilizer or in urine.

The fact that the yield increases due to the application of urine are greater than the increases due to either the nitrogen or potassium factor indicates that neither of these factors singly is responsible for the increased growth due to urine.

The small differences in yields in 1954 between the urine and the equivalent nitrogen fertilizer plus potassium fertilizer, and in 1955 between the urine and the urea plus potassium sulphate plots, strongly suggest that the effect of urine on pasture is largely due to its nitrogen and potassium content. This conclusion is further supported by the small differences in botanical composition between the urine and nitrogen/potassium plots in 1954. Clover made a much smaller contribution to the productivity of the pasture in 1955 and wherever nitrogen or urine was applied the sward was grass-dominant.

It has been suggested that the application of nitrogen to clover will reduce the capacity of the clover root nodule bacteria to excrete nitrogen (Willoughby (16)). It was also shown by Young (17) that 200 lb. nitrogen/acre reduced the number of nodules per gram root of clover.

In 1954 the reduction of yield increase per unit of urine when nitrogen fertilizer was applied was possibly due to a reduction in the activity of the clover root-nodule bacteria to excrete nitrogen caused by the increase in application of nitrogen (Blackman and Templeman (1)). In 1955 the clover content of the sward was much less on the plots receiving urine; hence the effect of applying further nitrogen on the clover was much less than in the previous year and a significant positive interaction was recorded, due to a large increase in grass production.

The depression of the percentage of clover in the pasture due to the return of urine has been recorded by many workers. It is considered that this effect is primarily due to the nitrogen in the urine stimulating grass growth

and thus increasing competition between grass and clover, to the detriment of the clover. Secondly the nitrogen will reduce the efficiency of the clover rhizobia and the vigour of the clover.

Doak (5) has shown that the auxin content of urine does depress clover, but under the field conditions of this experiment this was not apparent.

Undoubtedly better use of nitrogen dressings, as fertilizer or in urine, are made by a grass-dominant sward, as was shown by the greater responses to nitrogen in 1955.

Over the period of the trial the application of potassium sulphate increased the production of the sward by a mean of 15% in 1954 and 8% in 1955. The smaller increase in 1955 may be attributed to the lower clover content of the sward that year, since the greater part of the 1954 increase was due to increased clover production. Blaser and Brady (2) have shown that, in the absence of applied potassium, the dominant grass takes up much of the available potassium from a potassium-deficient soil and may leave insufficient for the clover; thus the application of potassium will help to maintain a higher clover content in the sward. This effect was apparent where potassium was applied to a sward receiving nitrogen fertilizer. It is probable that the potassium content of urine has a similar effect to that of potassium sulphate, because the clover content of the urine-treated sward was always higher than that of the sward treated with nitrogen fertilizer.

The application of potassium sulphate to a urine-treated sward did not appreciably increase production; it is probable that the potassium requirement of the pasture was largely met by the potassium content of the urine.

CONCLUSION

Since the water and indole acetic acid content of urine had no effect on pasture production or composition, it may be concluded that the effect of urine is very largely due to its content of nitrogen and potassium. The effect of urine will vary according to the botanical composition and production capacity of the sward. Urine may to a very large extent be replaced by fertilizers.

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MAGNESIUM, POTASSIUM, SODIUM AND CALCIUM CONTENTS OF HERBAGE AS INFLUENCED BY FERTILIZER TREATMENTS OVER A THREE-YEAR PERIOD

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Results are given showing the effects of applying nitrogen, phosphorus, potassium, sodium and magnesium on the yield and mineral composition of herbage cut repeatedly at the silage stage over a 3-year period. Grasses and clovers were separated before analysis. A combination of nitrogen and potassium was essential for the maintenance of high yields. Superphosphate did not increase dry-matter yields. 4 cwt. of common salt was ineffective, even under conditions of acute potassium deficiency; it reduced responses to potash and decreased yields when given with potash.

Ammonium sulphate and common salt greatly increased sodium uptakes and muriate of potash depressed them. Potassium contents were greatly reduced by repeated nitrogen applications and muriate of potash gave consistent and significant increases. Potassium-deficient grasses contained more sodium than potassium.

Ammonium sulphate increased magnesium contents and muriate of potash reduced them. There was a marked tendency for both effects to be more significant in late-season cuts. In late May the effects were small. 22 and 44 lb. Mg/acre as magnesium sulphate had variable effects on herbage magnesium. These changes are discussed in relation to hypomagnesaemia.

None of the fertilizer treatments altered the calcium contents of either grass or clover.

INTRODUCTION

There is increasing speculation that the extensive use of fertilizers on grassland alters the mineral content of the herbage in ways which are detrimental to animal health, and in particular that it increases the risk of hypomagnesaemia. Considering the importance of the subject, there is relatively little information concerning the effects of fertilizers on the mineral composition of herbage, and much of the earlier work has not involved the separate analysis of grasses and clovers. While any ill effect on livestock may derive principally from the physiology of the animal and from management, the part played by fertilizers should nonetheless be examined.

Stewart and Holmes (9) investigated the effects of heavy fertilizer applications over a period of years on herbage cut 5 times each year for silage. The rates used were 520 lb. N, 120 lb. P_2O_5 and 270 lb. K_2O per acre. They did not separate grass from clover prior to analysis and in consequence any changes in mineral composition could arise from botanical as well as manurial causes. They concluded that nitrogen fertilizers increased sodium, calcium and magnesium uptakes and decreased that of potassium. Potassium fertilizers increased herbage potassium but depressed the calcium, magnesium and sodium levels. Apart from an increase in copper contents resulting from nitrogen applications, the fertilizers did not influence the uptakes of trace elements.

Walker *et al.* (12, 13) found that ammonium sulphate had only minor depressive effects on calcium uptake by grasses and emphasized the importance of the grass/clover ratio in the calcium content of the sward. They also found that nitrogen increased potassium contents at the first cut in the season, but thereafter reduced them owing to the greater drain on soil potassium.

Watkins (14) also considered that herbage calcium was reduced by nitrogen, mainly by the increased growth of grass relative to clover. He also found that nitrogen stimulated potassium uptake at first but subsequently reduced it. Superphosphate increased magnesium absorption, but both nitrogen and

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potassium reduced it. It was found that a clover-dominant sward was more susceptible to a reduction in magnesium resulting from added potassium than a nitrogen-treated grass-dominant one.

This paper describes the effects of fertilizers on herbage, cut repeatedly over a 3-year period, in respect of yield and uptake of potassium, magnesium, calcium and sodium. A further communication will consider anion and trace-element compositions. Grasses and clovers have been analysed separately throughout.

Earlier work with turnips, kale and grass (Hemingway (3, 4, 5)) has shown that sodium uptakes are greatly influenced by fertilizers. There are also indications that sodium chloride may be a useful fertilizer for herbage. For example, Lynch (7) and Bell (1) in New Zealand have reported increases in the yield of pastures, especially under conditions of potassium deficiency, after applying common salt (referred to hereafter as salt). Lehr and Bussink (6) and Whehunt *et al.* (15) have found that salt increased the yield of clover, and Wallace *et al.* (11), York *et al.* (16) and Truog *et al.* (10) have found lucerne responsive. Salt has therefore been one of the fertilizer treatments in this current experiment.

EXPERIMENTAL

The experimental site was at Cochno, Dunbartonshire. The soil was a heavy loam, pH about 6·5, with satisfactory contents of readily-soluble phosphorus and potassium. The sward had been undersown the previous year with 3 cwt./acre of a NPK fertilizer and was predominantly a ryegrass/timothy/cocksfoot/wild-white-clover mixture.

The design of the experiment was a 2^5 factorial in 4 blocks of 8 plots with two 3-factor and one 4-factor interaction confounded between blocks. The treatments were the presence and absence of 3 cwt. ammonium sulphate, 3 cwt. superphosphate, 2 cwt. muriate of potash, 4 cwt. sodium chloride and 2 cwt. magnesium sulphate, applied in the spring of each year, with the exception of the nitrogen treatment which was repeated after each cut. The magnesium sulphate was $MgSO_4.7H_2O$ in 1957 and 1958 (=22 lb. Mg) and $MgSO_4$ in 1959 (=44 lb. Mg).

Four cuts of herbage (A, B, C and D) at the silage stage were taken during each of the 3 years. The first cut was in late May and the last in early September. The plots were each 0·005 acre, being 4 ft. wide and 54 ft. long. The central 3 ft.-strip of each plot was cut by an autoscythe and samples of the herbage were taken from the swath. Each sample was divided by hand in the laboratory into grasses and clovers for separate dry-matter determinations and mineral analysis. There were virtually no weeds.

There were the normal large increases in yield due to nitrogen at each cut and as a consequence the clover died out of the nitrogen-treated plots at the end of the first year of the experiment. Signs of potassium deficiency were obvious at the end of the first year on the plots receiving nitrogen but no potassium. During the second and third years severe signs of potassium deficiency developed on these plots and there were marked reductions in yield. In the absence of nitrogen, potassium maintained a sward higher in clover, but superphosphate had no obvious effect. On the potassium-deficient plots by the third year the sown grasses were being replaced by *Agrostis tenuis* and *Festuca rubra*.

Methods of analysis

Determinations of potassium, sodium, calcium and magnesium were undertaken by the rapid scheme of analysis previously described (Hemingway (3)).

RESULTS

Dry-matter yields

Table 1 summarizes the separate effects of the fertilizers on the dry-matter yields of grass and clover. Only those interactions which were significant or consistent have been listed.

Ammonium sulphate gave large and significant ($P = 0{\cdot}01$) increases in yield of grass at each cut, but in 1957 it depressed clover to such an extent that it subsequently died out on those plots.

TABLE 1. Dry matter yields (cwt./acre)

	1957				1958				1959			
	A	B	C	D	A	B	C	D	A	B	C	D
GRASS												
Mean yield	27·84	8·53	10·58	5·29	13·18	13·06	8·94	7·95	17·00	9·51	9·43	5·22
Response to												
Salt	−1·16	−0·01	−0·16	−0·09	−1·39	0·19	−0·20	−0·56	−1·02	−0·47	−0·36	−0·51
Magnesium sulphate	−0·76	−0·19	0·46	0·08	0·40	−1·10	0·24	0·13	0·20	−0·41	0·01	−0·01
Ammonium sulphate	15·08**	9·17**	11·86**	4·08**	9·29**	10·11**	10·11**	4·50**	8·75**	9·26**	9·12**	3·84**
Superphosphate	1·36	−0·09	0·66	0·07	2·81**	−0·31	−0·51	−0·36	2·75**	−0·34	1·03	−0·22
Muriate of potash	−0·14	−0·04	0·73	0·51*	2·30**	−0·14	1·71**	1·89**	6·00**	1·68*	1·37**	1·46**
Standard error ±	1·34	0·45	0·63	0·25	0·77	0·44	0·28	0·60	0·71	0·69	0·46	0·44
Interactions												
N/K	−1·19	0·04	0·09	0·12	0·65	0·91	1·96**	1·21	3·45**	1·23	2·01**	1·94**
K/NaCl	−0·66	0·14	−0·98	−0·72*	−2·52*	−0·76	−1·40**	−1·47**	−2·04	−1·71	−0·12	−0·84
CLOVER												
Mean Yield	4·31	3·97	3·46	0·80	0·35	0·67	0·71	0·68	1·03	1·31	1·67	1·42
Response to												
Salt	−0·70	−0·15	−0·11	−0·04	−0·30**	−0·32**	−0·27**	−0·12	−0·05	0·26**	1·21**	0·59**
Magnesium sulphate	−0·06	0·38	0·21	−0·01	0·00	0·20	0·03	0·10	0·01	0·06	−0·01	0·21
Ammonium sulphate	−2·14**	−4·48**	−4·89**	−1·08**	—	—	—	—	—	—	—	—
Superphosphate	0·24	−0·06	−0·06	0·02	0·03	0·05	−0·05	0·03	0·20	0·36**	0·26*	0·16
Muriate of potash	0·16	−0·24	0·18	0·20*	0·13**	−0·07	0·13*	0·50**	1·62**	1·26**	1·21**	1·14**
Standard error ±	0·34	0·28	0·22	0·07	0·04	0·05	0·05	0·06	0·10	0·08	0·10	0·08
Interactions												
K/NaCl	−0·24	−0·03	0·26	0·06	−0·12	0·33**	0·03	−0·02	0·22	0·31*	0·49*	0·04

The herbage did not respond to muriate of potash until the fourth cut in 1957 but thereafter it substantially and significantly increased the yield of both grass and clover. There were large and frequently significant positive N/K interactions. Nitrogen without potash had much reduced effects on the yield of grass dry-matter during 1958–9 and these plots showed severe potassium deficiency.

When averaged over all the treatments, salt had little effect on yields of grass; it depressed clover yields in 1957–8 but increased them in 1959. There were substantial negative K/NaCl interactions for grass. The K/NaCl interactions for clover were smaller and much less consistent.

Table 2 illustrates in more detail the responses to salt and potash in the presence and absence of each other. The consistent negative K/NaCl interactions for the grass lead to two main conclusions. Firstly, muriate of potash greatly increased yields in the absence of salt, but did not do so (with two exceptions in 1959) when given with salt. Also, salt only increased grass yields in the absence of potash: it significantly reduced them when given with potash. Thus adding salt presumably reduces the effectiveness of potash applications under conditions of potassium deficiency. Salt alone did little to increase grass yields and may significantly depress them if given with muriate of potash. It is possible that the adverse effects of salt plus muriate of potash may be due to chloride injury. Together, at the rates used, they supply 370 lb. Cl, which is equivalent to that in 7·75 cwt. of muriate of potash. Chloride analyses are being undertaken to check this possibility.

The interactions between salt and potash with regard to clover yields were very irregular and, in contrast to those with grass, they were frequently significantly positive. There was no tendency for salt to depress responses to potash. Salt alone did not increase yields until

TABLE 2. Dry matter responses to 2 cwt. muriate of potash and 4 cwt. salt (cwt./acre)

GRASS

		Mean Yield	Response to K		Response to Na	
			No Na	With Na	No K	With K
1957	A	27·84	0·52	−0·80	0·50	−1·82
	B	8·53	−0·18	0·10	−0·15	0·13
	C	10·58	1·71	−0·25	0·82	−1·14
	D	5·29	1·23**	−0·21	0·63	−0·81*
1958	A	13·18	4·82**	−0·22	1·13	−3·91**
	B	13·06	0·62	−0·90	0·95	−0·57
	C	8·94	3·11**	0·31	1·20*	−1·60**
	D	7·95	3·36**	0·33	0·91	−2·03*
1959	A	17·00	8·04**	3·96**	1·02	−3·06*
	B	9·51	3·39**	−0·03	1·24	−2·18*
	C	9·43	1·42*	1·25*	−0·24	−0·48
	D	5·22	2·28**	0·64	0·31	−1·33*

CLOVER

		Mean Yield	Response to K		Response to Na	
			No Na	With Na	No K	With K
1957	A	4·31	0·40	−0·08	−0·46	−0·84
	B	3·97	−0·21	−0·27	−0·12	−0·18
	C	3·46	−0·08	0·44	−0·37	0·15
	D	0·80	0·14	0·26	−0·10	0·26
1958	A	0·35	0·25**	0·01	−0·18*	−0·42**
	B	0·67	−0·40**	0·26**	−0·65**	0·01
	C	0·71	0·10	0·16*	−0·30**	−0·24**
	D	0·68	0·52**	0·48**	−0·10	−0·14
1959	A	1·03	1·82**	1·40**	0·17	−0·27
	B	1·31	0·95**	1·51**	0·57**	−0·05
	C	1·67	0·72**	1·70**	0·72**	1·70**
	D	1·42	1·10**	1·18**	0·55**	0·63**

1959. In this experiment the salt was applied on a wet day, as earlier work (5) has shown that in a finely-powdered form it may reduce the clover by leaf scorch. Nonetheless, salt reduced clover yields in 1957 and 1958, although there was no leaf damage.

Superphosphate increased grass yields only at the first cut in each year; otherwise its general effect was negligible. It did not increase clover yields until the third year of the experiment.

The small dressings of magnesium sulphate did not increase yields.

Dry-matter composition

(a) *Potassium* (*Table 3*)

Ammonium sulphate and muriate of potash had the greatest effect on potassium uptake. From the second sampling in 1957 onwards ammonium sulphate produced large and highly significant reductions. These increased steadily during each year but there was some recovery between one year and the next. Acute visual symptoms of potassium deficiency were found on the plots receiving nitrogen only, but not where nitrogen and potash were applied together. Values as low as 0·5–0·6% K were recorded regularly in the grass samples on the former plots in 1959.

Muriate of potash increased potassium uptakes consistently, and significantly, over the whole period of the experiment. Responses were greatest in the clover and by 1959 plots with potassium were running about 0·9 and 1·2% K higher, for grass and clover respectively, than those without.

Salt had only small effects on potassium uptake. In 1958 it tended to reduce the potassium content of the grass whereas in 1959 it increased levels in clover significantly. It does not seem to have had any consistent "potassium sparing" effect.

Superphosphate also had only a small influence on potassium contents. It tended on the whole to reduce uptakes by about 0·1% K in the grass. The small dressing of magnesium sulphate was without effect on potassium levels.

(b) *Sodium* (*Table 4*)

The mean sodium contents rose steadily from the first to the fourth cuts in each year and from one year to another. From an initial mean level in the grass of 0·144% it rose to 0·537%, the respective figures for clover being from 0·273% to 0·506%.

Salt itself had large and consistently significant ($P = 0{\cdot}01$) incremental effects on both grass and clover sodium contents. The increases were generally about 50% of the respective mean values for grass and around 30% for clover.

Ammonium sulphate had even greater effects. For grass the increases were about equal to the mean levels at each cut. There were, furthermore, large and significant positive N/NaCl interactions.

Muriate of potash greatly reduced sodium uptakes in both grass and clover. 2 cwt. of muriate of potash on the whole reduced levels by about as much as 4 cwt. of salt increased them. There were consistent negative N/K interactions.

Superphosphate and magnesium sulphate had no outstanding effects on either grass or clover.

(c) *Magnesium* (*Table 5*)

In each year the magnesium content of the grass rose considerably from the first to the fourth cut and the general level rose from 1957 to 1958 and again from 1958 to 1959. This trend did not occur in the clover samples, in which it fell not only as each season progressed but also from the first year of the experiment to the last.

Ammonium sulphate increased magnesium levels in the grass by amounts which were highly significant. During each of the three years the increments became greater from first to fourth cut and in both 1957 and 1959 the increases at the first cut were extremely small. By the last cut in each year the increases were about 0·040 to 0·050%. In 1957 the nitrogen effect on clover magnesium was irregular; it decreased the magnesium content at the first sampling, but thereafter enhanced it.

TABLE 3. Percentage of potassium in the dry matter

	1957				1958				1959			
	A	B	C	D	A	B	C	D	A	B	C	D
GRASS												
Mean % K	1·63	1·96	2·43	2·09	2·01	1·87	1·85	1·90	1·60	1·45	1·67	1·45
Response to												
Salt	0·01	0·02	−0·04	−0·04	0·01	−0·17*	−0·11	−0·21**	0·02	−0·02	0·16	0·12
Magnesium sulphate	−0·01	0·05	−0·04	0·09	0·08	0·16	0·03	0·07	0·02	−0·03	0·00	0·00
Ammonium sulphate	0·06	−0·15*	−0·75**	−0·71**	−0·13**	−0·25**	−0·81**	−1·18**	−0·39**	−0·52**	−1·29**	−1·41**
Superphosphate	−0·13	−0·03	0·04	−0·11	−0·14**	−0·04	0·03	−0·16*	−0·04	−0·02	−0·10	−0·15*
Muriate of potash	0·24**	0·24**	0·59**	0·53**	0·78**	0·89**	0·77**	0·81**	0·94**	0·80**	0·89**	0·81**
Standard error ±	0·06	0·06	0·10	0·08	0·04	0·07	0·06	0·07	0·06	0·07	0·11	0·07
CLOVER												
Mean % K	1·85	1·65	1·86	1·55	1·94	1·76	1·62	1·66	1·77	1·64	2·02	1·72
Response to												
Salt	0·06	0·02	0·05	0·01	0·08	0·01	−0·03	−0·05	0·10	0·21*	0·26**	0·34**
Magnesium sulphate	−0·07	0·11	0·08	0·11	0·02	0·00	−0·12	0·07	0·04	−0·04	−0·23*	0·05
Ammonium sulphate	0·08	−0·05	−0·22**	−0·20*	—	—	—	—	—	—	—	—
Superphosphate	−0·05	−0·05	0·01	0·00	−0·11	−0·17*	−0·03	−0·15	0·02	−0·04	0·04	−0·11
Muriate of potash	0·53**	0·44**	0·55**	0·47**	1·05**	0·90**	0·81**	0·89**	1·15**	1·06**	1·42**	1·31**
Standard error ±	0·07	0·07	0·07	0·07	0·05	0·06	0·06	0·10	0·05	0·08	0·07	0·07

TABLE 4. Percentage of sodium in the dry matter

	1957				1958				1959			
	A	B	C	D	A	B	C	D	A	B	C	D
GRASS												
Mean % Na	0·144	0·224	0·371	0·446	0·380	0·434	0·495	0·514	0·416	0·416	0·510	0·537
Response to												
Salt	0·070**	0·105**	0·136**	0·035	0·138**	0·249**	0·247**	0·247**	0·275**	0·157**	0·269**	0·361**
Magnesium sulphate	−0·006	−0·042*	−0·050	−0·068*	−0·019	−0·027	+0·017	−0·018	−0·035	−0·026	−0·039	0·019
Ammonium sulphate	0·087**	0·248**	0·432**	0·392**	0·313**	0·528**	0·637**	0·514**	0·348**	0·424**	0·568**	0·438**
Superphosphate	−0·005	−0·021	−0·016	−0·039	0·049*	0·004	0·036	−0·027	0·045	0·018	−0·005	0·023
Muriate of potash	−0·062**	−0·097**	−0·163**	−0·158**	−0·286**	−0·294**	−0·236**	−0·236**	−0·314**	−0·223**	−0·239**	−0·242**
Standard error ±	0·018	0·019	0·034	0·029	0·025	0·034	0·037	0·031	0·036	0·023	0·047	0·016
Consistent interactions												
K/NaCl	0·001	0·059*	0·047	−0·001	0·086*	0·183**	0·216**	0·149**	0·181**	0·158**	0·256**	0·308**
N/K	0·000	−0·058*	−0·077*	−0·118*	−0·098*	−0·162**	−0·133*	−0·036	−0·075	−0·078*	−0·056	0·048*
CLOVER												
Mean % Na	0·273	0·265	0·231	0·248	0·209	0·247	0·273	0·292	0·279	0·328	0·343	0·506
Response to												
Salt	0·196**	0·108**	0·112**	0·088**	0·105**	0·073**	0·091**	0·135**	0·102**	0·070**	0·073**	0·200**
Magnesium sulphate	−0·012	−0·027	−0·013	−0·027	−0·047*	0·015	−0·006	0·000	−0·021	−0·037	−0·022	0·000
Ammonium sulphate	0·065*	0·066**	0·111**	0·088**	—	—	—	—	—	—	—	—
Superphosphate	0·004	0·002	0·024	−0·010	−0·050*	−0·020	0·021	0·025	0·015	0·038	0·000	0·030
Muriate of potash	−0·029	−0·082**	−0·094**	−0·114**	−0·157**	−0·117**	−0·181**	−0·212*	−0·187**	−0·282**	−0·350**	−0·380**
Standard error ±	0·024	0·015	0·021	0·018	0·020	0·021	0·015	0·014	0·015	0·020	0·022	0·017

TABLE 5. Percentage of magnesium in the dry matter

	1957				1958				1959			
	A	B	C	D	A	B	C	D	A	B	C	D
Grass												
Mean % Mg.	0·090	0·134	0·180	0·177	0·100	0·100	0·148	0·156	0·136	0·166	0·206	0·217
Response to												
Salt	−0·006	−0·005	−0·005	−0·013*	−0·009	−0·003	−0·029**	−0·004	−0·021*	−0·028**	−0·030**	−0·035**
Magnesium sulphate	0·001	−0·008	−0·003	−0·001	0·012*	0·005	0·002	0·010*	0·009	0·013	0·021*	0·038**
Ammonium sulphate	0·002	0·016*	0·015*	0·043**	0·018**	0·025**	0·043**	0·042**	0·011	0·047**	0·049**	0·054**
Superphosphate	−0·002	−0·007	−0·002	0·007	−0·007	−0·011	−0·001	−0·006	−0·005	0·006	0·001	0·005
Muriate of potash	−0·004	−0·023**	−0·023**	−0·019**	−0·021**	−0·008	−0·033**	−0·025**	−0·004	−0·033**	−0·030**	−0·019**
Standard error ±	0·004	0·006	0·006	0·005	0·005	0·006	0·007	0·004	0·010	0·006	0·010	0·005
Consistent interactions K/NaCl	0·008	0·009	0·022**	0·011*	0·013*	0·002	0·010	0·013**	0·014	0·005	0·014	−0·005
Clover												
Mean % Mg.	0·221	0·229	0·259	0·207	0·239	0·222	0·214	0·142	0·201	0·195	0·190	0·204
Response to												
Salt	−0·007	−0·012*	0·003	−0·001	−0·015*	−0·012	0·009	−0·021**	−0·015*	−0·029**	−0·005	−0·027**
Magnesium sulphate	0·017*	0·000	0·006	0·005*	0·041**	−0·002	0·012	0·016*	0·022**	0·017*	0·026*	0·016*
Ammonium sulphate	−0·021**	0·014**	0·019**	0·016	—	—	—	—	—	—	—	—
Superphosphate	−0·002	−0·005	−0·006	−0·002	0·016*	0·008	−0·016	−0·006	−0·003	−0·004	0·001	0·002
Muriate of potash	−0·014*	−0·019**	−0·024**	−0·010**	−0·009	−0·047**	−0·025**	−0·024**	−0·015*	−0·022*	−0·034**	−0·022**
Standard error ±	0·006	0·004	0·007	0·002	0·006	0·007	0·008	0·006	0·006	0·008	0·007	0·006
Consistent interactions K/NaCl	0·001	0·012*	0·025**	−0·014	−0·007	0·021*	0·005	0·008	0·014	0·006	0·006	−0·008

TABLE 6. Percentage of calcium in the dry matter

	1957				1958				1959			
	A	B	C	D	A	B	C	D	A	B	C	D
Grass												
Mean % Ca	0·45	0·63	0·69	0·74	0·31	0·28	0·42	0·39	0·25	0·26	0·33	0·36
Response to												
Salt	−0·01	0·04	0·00	−0·04	−0·01	0·00	−0·02	0·00	−0·03	−0·03	−0·05*	−0·05
Magnesium sulphate	−0·02	−0·07**	−0·04	−0·01	−0·01	−0·01	−0·01	−0·02	−0·01	−0·01	−0·01	−0·00
Ammonium sulphate	0·04*	0·03	0·00	0·08**	0·03	0·04	0·05	−0·02	0·01	0·02	0·01	0·00
Superphosphate	−0·01	−0·02	0·02	0·01	0·01	0·03	−0·01	−0·02	0·02	0·02	0·00	0·00
Muriate of potash	−0·02	0·03	−0·04	0·00	−0·01	0·00	−0·02	−0·01	−0·04	−0·03	−0·05*	−0·03
Standard error ±	0·02	0·02	0·03	0·02	0·02	0·03	0·03	0·02	0·02	0·02	0·02	0·03
Clover												
Mean % Ca	2·03	1·70	1·85	1·83	1·18	1·13	1·18	1·01	0·99	0·78	0·81	0·73
Response to												
Salt	−0·12	−0·06	−0·01	0·03	−0·04	−0·04	0·02	−0·01	−0·05	−0·10	−0·06	−0·07
Magnesium sulphate	0·00	0·00	0·05	−0·01	−0·02	−0·04	−0·03	−0·01	−0·01	−0·02	−0·03	−0·03
Ammonium sulphate	−0·14	−0·03	−0·02	0·04	—	—	—	—	—	—	—	—
Superphosphate	−0·02	0·00	0·04	−0·05	0·12*	0·00	−0·03	0·02	0·04	0·05	0·03	0·02
Muriate of potash	0·01	0·01	−0·06	−0·07	−0·05	−0·03	−0·02	0·02	0·02	0·01	−0·08*	0·01
Standard error ±	0·07	0·04	0·03	0·06	0·05	0·05	0·03	0·02	0·03	0·05	0·03	0·04

Muriate of potash invariably reduced magnesium levels in both grass and clover by amounts ranging up to about 0·025% Mg. As with ammonium sulphate, much the greater effects were found in the second and subsequent cuts in each year. In 1957 and 1959 the reductions in grass magnesium in late May were only 0·004% Mg.

Salt also reduced magnesium levels significantly, but to a rather smaller extent than did muriate of potash. Again there was a tendency for the reduction in the first sample each year to be smaller than for subsequent ones. The K/NaCl interactions were positive, indicating that their effects are additive.

Magnesium sulphate supplying 22 lb. Mg/acre did not increase grass magnesium in 1957, but it had a small effect in 1958. On the other hand it always increased clover magnesium, particularly at the first cut each year. When the rate was increased to 44 lb. Mg in 1959 it increased grass magnesium most at the fourth cut, but enhanced clover magnesium throughout the year by about 0·020%.

Superphosphate did not alter magnesium uptakes in either grass or clover.

(d) *Calcium* (*Table 6*)

The calcium contents of both grass and clover fell steadily from 1957 to 1959. The mean content in grass was about 0·60% in 1957 but only 0·30% in 1959 and the amounts in clover fell from about 1·8% to 0·8%. The soil did not become any more acid and there is no obvious explanation for this steady fall in calcium contents.

Fertilizers had remarkably little influence on calcium uptake and no significant trends were found. It is clear that the calcium content of herbage depends more on the effects which fertilizers have on the grass/clover ratio than on the uptakes of individual plants—a view which has been expressed by several earlier workers.

DISCUSSION

Dry-matter yields

This experiment has confirmed the work of Stewart and Holmes (9) in showing that continuous production of herbage is primarily dependent on an adequate supply of nitrogen and potassium. Superphosphate had no incremental effect over the 3 years. Whilst a good supply of phosphate may be necessary for the proper establishment of a sward, it was clearly not required for maintenance of yield.

During 1958 and 1959 severe potassium deficiency developed on the plots which had not been treated with potassium. Salt was not able to increase yields under these conditions. There were consistent and large negative K/NaCl interactions which were frequently significant. Salt depressed grass yields when given together with potash. It also markedly reduced the responses of grass to potash. On the other hand it increased clover yields in the third year. This experiment and earlier single-year ones (5) do not lead to the conclusion that salt is a useful fertilizer for grass either in its own right or as a partial substitute for potash.

Mineral composition

The two most variable mineral elements were sodium and potassium. Fig. 1 shows their general inverse relationship in both grass and clover under differing manurial conditions. Each point is the mean of the appropriate treatment itself and with magnesium sulphate, or superphosphate, or magnesium sulphate plus superphosphate, i.e. the mean of four plots.

For the plots with no nitrogen, 2 cwt. of muriate of potash maintained a level of between 2 and 3% K over the 3 years but on the no-fertilizer and salt-alone plots there was a slight annual fall. The grass normally contained more potassium than the clover. 2 cwt. of muriate of potash annually could not maintain the initial level of about 2% K when 3 cwt. of ammonium sulphate was given for each cwt. There was then a steady decline from one year to another. During 1957, the N+K and the N+K+salt treatments raised potassium contents somewhat, but in 1958 and 1959 there were rapid falls. The mean total dry-matter yields in 1957, 1958 and 1959 were 53·1, 43·1 and 41·1 cwt. and this fall may have been due to a continuing reduction in soil potassium. 2 cwt. muriate of potash maintained or slightly increased the original

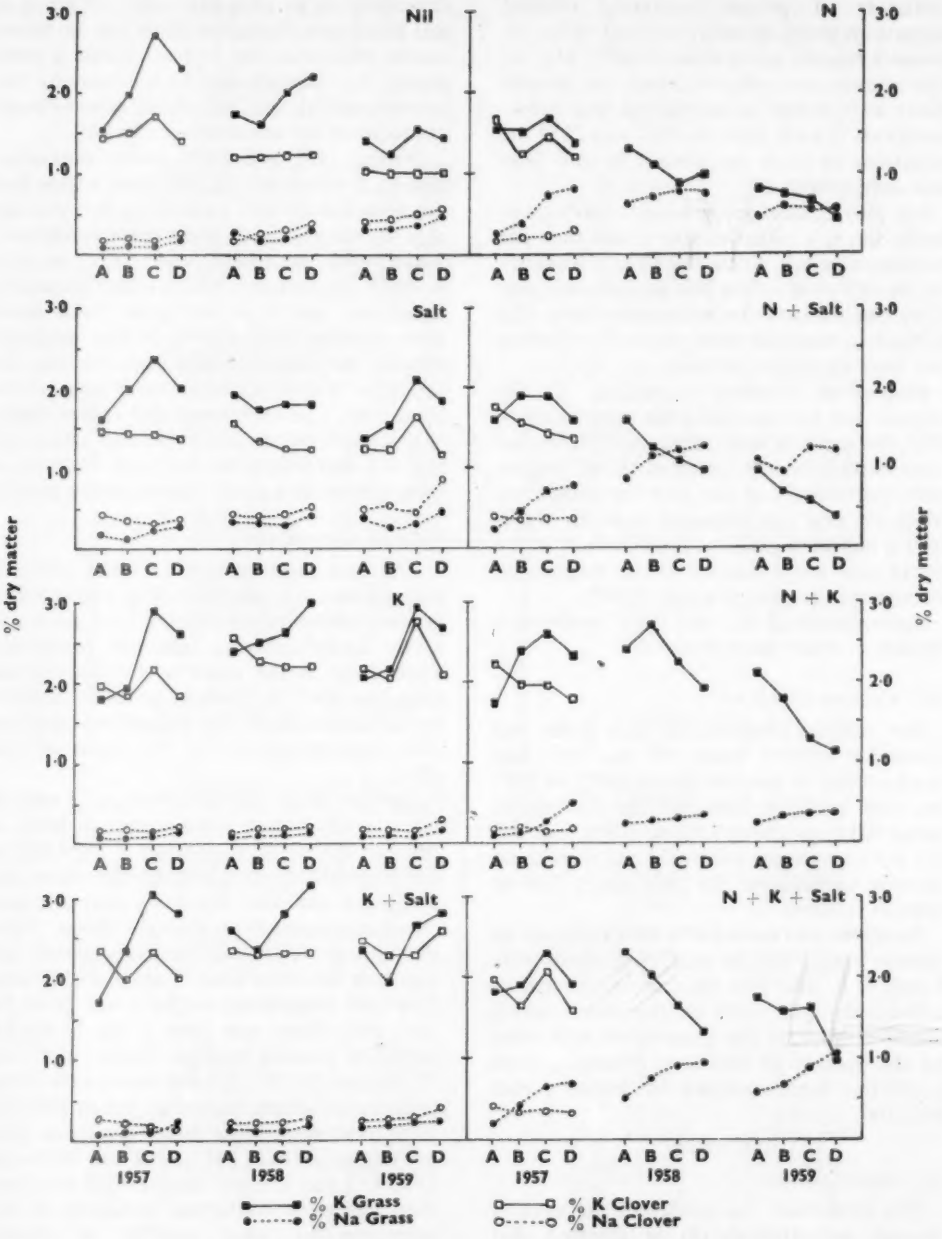

Fig. 1. Mean contents of sodium and potassium in dry matter

level over the whole period, but the addition of nitrogen greatly reduced it.

Sodium levels altered in inverse ratio to those of potassium. Fig. 1 shows that in every case as herbage potassium figures were reduced, sodium levels rose. The extremes for this are found in the N, N+salt and N+K+salt plots, where in 1958 the sodium levels approached those for potassium and in 1959 the dry matter contained more sodium than potassium.

It would appear that uptake of sodium is controlled by the potassium supply. As the soil potassium status falls, more sodium enters the plant and vice versa. It is clear, however, that potassium is the preferred ion. Increases in sodium uptake are also connected with the nitrogen supply (Fig. 1 and Table 4). Nitrogen seems to exert some influence of its own, associated with increasing growth, which is not due solely to its eventual depressive effect on potassium uptake. Thus, the sodium contents of grass were always higher on the nitrogen-treated plots, even in 1957 before the general potassium content of the herbage started to fall.

Very similar results to these have been previously reported for kale (4) and for single-year experiments with grass (5).

Patterson and Crichton (8) have recently successfully used salt in the control of hypomagnesaemia in large numbers of cattle on spring grass. They have suggested that hypomagnesaemia may be increased by low sodium levels in herbage and quote a number of Dutch workers on this point (e.g. Frens, (2)). They also suggest that potassium applications to herbage should be such as not unduly to depress herbage sodium, but they do not quote any data for the sodium content of their pastures.

This experiment indicates that sodium levels are raised by nitrogen to at least as great an extent as they are depressed by potassium. It is hard therefore to see how reasonable applications of both together could markedly reduce sodium contents.

Magnesium

There are many references to the general depressive effect of muriate of potash on the magnesium uptake of many varied crops. This experiment confirms this in so far as it affects herbage cut repeatedly for silage. There was also a reduction in magnesium from the application of salt, and the K/NaCl interactions were generally positive.

Reductions were smallest at the first cut in the case of both grass and clover (with the exception of the grass in 1958). In both 1957 and 1959 there were only very small and non-significant reductions in grass magnesium in late May, although subsequently the falls were appreciable.

There is currently a great deal of advice offered to the effect that autumn or winter applications of muriate of potash are to be preferred to spring applications, in the belief that such timing will have less depressive effect on herbage magnesium and will, in consequence, help in the problem of hypomagnesaemia. This experiment would seem to question the belief that the greatest herbage magnesium reductions come shortly after the application of potash. There seems to be no published work comparing spring- and autumn-applications of muriate of potash, but experiments on this subject are current in this Department.

Ammonium sulphate consistently increased herbage magnesium, with the exception of the first clover cut in 1957 where there was a marked reduction in growth. Here again the increases were greater in the second, third and fourth cuts each year. It would appear that at the rates used the effects of nitrogen and potassium applied together on herbage magnesium are likely to be small. Very similar results have been found in other grass experiments (5). In the spring, clover contains appreciably more magnesium than does grass, but at the end of the season their contents may be very similar (Table 5).

Magnesium sulphate at rates of 22 and 44 lb. Mg/acre increased magnesium uptakes, but somewhat erratically. There were significant increases in the clover at the first and last cuts in each year and throughout the whole of 1959. In 1957 the grass failed to respond, but there were significant increases in both 1958 and 1959.

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THE RESPONSE OF SOME HILL PASTURE TYPES TO LIME AND PHOSPHATE

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A study was made of the responses of four upland soil- and vegetation-types to applied lime and phosphate in the north of Scotland. Light and heavy dressings were used, the former at a rate which might be economically considered for aircraft application. Two experiments were laid down on graminaceous communities and two on contrasting types of Callunetum. The low rate of lime produced little measurable soil response, whereas the high rate induced marked and persistent effects. In terms of botanical response, however, the high rate of liming showed little advantage over the low rate in the presence of phosphate at the two grassland sites. Only very minor vegetation effects were observed at the *Calluna* centres, particularly where the community was in the mature stage. The results emphasize the importance of an ecological approach to upland pasture improvement, involving a knowledge of the specific responses of different plant communities to fertilizer application, combined with an appropriate measure of stock control.

INTRODUCTION

The effects of lime, fertilizers and management practices on semi-natural hill-pasture types have been studied by several investigators in the last thirty years. Most of this work, however, carried out by Stapledon and his co-workers, relates to Wales, where it was clearly shown that marked yield responses could be obtained by the application of lime and fertilizer (19, 2, 12). It was further demonstrated that profound floristic changes could be induced by such treatments when combined with severe defoliation or controlled grazing. Certain grassland communities were shown to be dynamically related, so that a sequence of communities developed with improved fertility status (13). When treatments persisted for long enough, species characteristic of lowland grassland appeared in swards developed serally from *Molinia* or *Festuca/Agrostis* pasture (14). Concurrently, it was shown (5, 4, 15) that the chemical characteristics of the herbage, especially the nitrogen and mineral content, could be modified by these treatments.

There is little information in the literature relating to the effects of lime and fertilizer treatments on the chemical status of upland soils. Davies (3) gives some figures for three pasture types after periodic treatment over nine years with heavy dressings of lime and fertilizers. These showed that the calcium, potassium and phosphorus status of the soils were considerably enhanced. In contrast, Heddle and Ogg (9) state in relation to manurial experiments on the Pentland Hills that, "even heavy dressings of lime have had remarkably little effect on either the acidity or lime requirement of the soil". The same authors, however, give figures showing a marked effect of mineral-rich irrigation water on the chemical status of similar soils (10).

Techniques of improvement based on these principles have been successfully applied on numerous occasions to the deeper soils of lower hill slopes. In general, however, surface treatment, with or without seeding, has not been so widely employed as the more drastic and quicker method of ploughing and reseeding which has resulted in the enclosure, on many hill farms, of the lower slopes capable of supporting productive grassland. Apart from the normal practices of burning and draining,

little attempt has been made to improve the much larger areas of unenclosed pasture. Indeed, the manner in which this might be achieved has never been seriously studied. Nevertheless, selected areas of the more responsive vegetation might be profitably top-dressed with lime and fertilizer, provided a greater measure of stock control could be introduced and that the problem of access and distribution on difficult terrain could be overcome.

The success of the aeroplane in top-dressing hill country in New Zealand (18) made it inevitable that consideration would be given to the possible application of this technique to British hill land (1). Dropping trials were carried out on Plynlimon, Montgomeryshire, in 1950, using a Bristol Freighter, and several further experimental approaches have since been made. Under New Zealand conditions, the principal factor limiting pasture production is phosphorus deficiency, which can be corrected by the application of 2–3 cwt. per acre of superphosphate. In Britain, the response of hill pastures to phosphorus is limited by the more acid soil conditions which generally preclude the establishment of white clover (*Trifolium repens*). The fact that heavy lime dressings are also needed makes aerial top-dressing very much more costly.

Although the early work referred to provides a useful indication of the response of certain types of hill vegetation to lime and fertilizer, the applications given were heavy and frequent. In addition, these pastures were primarily of the *Festuca/Agrostis*- or *Molinia*-dominant types. In view of this, a series of pilot experiments was laid down in 1952 in Scotland, England and Wales, under the auspices of the Hill Farm Research Committee, to determine the response of some vegetation types to low rates of lime and phosphate. This account deals with four of these trials which were located in the North of Scotland.

MATERIALS

A description of the four experimental sites is given in Table 1.

Soils

The results of pretreatment soil analysis are given in Table 2. The profiles are described in the Appendix.

The analysis of samples from sites A and B are typical of those for upland soils bearing Callunetum in northern Scotland. They show very low pH values and contain extremely small amounts of readily soluble lime and phosphate. Loss on ignition varies with the depth of the A_O horizon which is obviously better developed at Site A (see Appendix).

TABLE 1. General description of experimental sites

	Centre	Soil	Vegetation	Elevation (ft.)	Rainfall (in.)
A.	Glensaugh, Kincardineshire	Peaty podsol with thin iron pan on quartz-mica schist till. Drainage—free below pan.	*Calluna* dominant	1000	35
B.	Tulloch Moor, Boat of Garten, Inverness-shire	Iron podsol on fluvio-glacial sand and gravel. Drainage—free.	*Calluna* dominant	750	30
C.	Huntly, Aberdeenshire	Brown forest soil (low base status) on quartz-mica schist till. Drainage—free	*Agrostis/Festuca*	700	35
D.	Tomdhu, Boat of Garten, Inverness-shire	Alluvium. Drainage—imperfect	*Nardus* dominant	650	30

TABLE 2. Soil analysis prior to applying treatments (mean of four blocks)

Site	pH	CaO*	K_2O*	P_2O_5*	% loss on ignition
A	4·2	50	21	1·3	37
B	4·3	79	13	2·5	15
C	5·1	44	14	1·2	8
D	5·3	68	8	2·5	14

*2·5% acetic acid extracts, expressed as mg./100 g. air-dry soil (<2 mm.)

The soils from the grassland sites (C and D) are less acid, but the CaO and P_2O_5 values in the surface horizons are again very low. The potash figures for all samples are not unduly low.

Vegetation

(1) *Calluna sites* (A and B). At site A, a severe fire in 1950 completely destroyed the vegetation, which was recolonizing slowly at the time the experimental treatments were applied. In this pioneer phase (16), the regenerating *Calluna* showed a very low percentage ground cover and was associated with a number of other early colonizers (Plate 1). The principal associated species were *Erica cinerea*, *Agrostis canina*, *A. tenuis*, *Carex panicea* and *C. pilulifera*. Other characteristic species included *Galium hercynicum*, *Vaccinium myrtillus*, *Anthoxanthum odoratum*, *Festuca ovina*, *Deschampsia flexuosa* and *Sieglingia decumbens*.

The vegetation at site B was burned approximately six years before the experiment began, and by 1952 recolonization was well advanced (Plate 2) and only a small proportion of the ground was bare. *Calluna* completely dominated the upper layer of the community (Plate 3). The principal subsidiary species were *Arctostaphylos uva-ursi* and *Vaccinium vitis-idaea*. Other species included *Genista anglica*, *Potentilla erecta*, *Lotus corniculatus*, *Agrostis canina*, *Deschampsia flexuosa* and *Festuca ovina*. A particularly vigorous though discontinuous moss layer composed mainly of *Hypnum cupressiforme* was also present.

Both these centres lie on extensive hill-sheep grazings.

(2) *Grassland sites* (C and D). Dominance was shared at site C by *Agrostis tenuis*, *Festuca* spp. (*ovina* and *rubra*) and *Anthoxanthum odoratum*. The community was fairly rich in subsidiary species, the most frequent being *Galium hercynicum*, *Lotus corniculatus*, *Agrostis canina*, and *Holcus* spp. *Trifolium repens* was sparsely represented. Several moss species also occurred, the most abundant being *Rhytidiadelphus squarrosus*.

At Tomdhu (D) *Nardus stricta* was dominant (Plate 4). Floristically this community was very rich, the most frequent subsidiary species being *Agrostis tenuis*, *A. canina*, *Succisa pratensis*, *Juncus squarrosus*, *Anthoxanthum odoratum*, *Festuca ovina*, *F. vivipara*, *Sieglingia decumbens*, *Potentilla erecta* and *Erica tetralix*. *Trifolium repens* was represented very occasionally in local pockets and *T. pratense* was very rare.

The site at Huntly (C) was open to unrestricted grazing by hill sheep, but grazing intensity was considerably greater than at either of the *Calluna* sites. The most intensive grazing occurred at Tomdhu where both sheep and cattle had access to the plots.

METHODS

Layout. The treatments comprised zero, light and heavy dressings of lime and phosphate, giving nine factorial combinations. Calcium was applied as ground limestone (0, 4 and 30 cwt. CaO/acre) and phosphorus as superphosphate (0, 50 and 150 lb. P_2O_5/acre).

The experiments were laid out as randomized blocks with four replicates, each plot measuring 7×57 yd., or $\frac{1}{12}$ acre. (At centres B and D a systematic layout was adopted for practical reasons). The treatments were applied in the spring of 1952 and subsequent evaluation was based on botanical composition and chemical analysis of the soils and herbage. Analyses of variance were carried out where appropriate and the angular transformation of percentage data was used to equalize variances (17).

Soil analysis. Random soil samples were taken to a depth of 6 in. with a soil auger. In addition to the pre-treatment sampling, each plot was subsequently sampled in 1954, 1956 and 1959

and determinations made on air-dry soil (<2 mm.) for pH, % loss on ignition, and CaO and P_2O_5 extracted by 2·5% acetic acid (21).

Botanical analysis. Botanical analyses were carried out with a point quadrat using five points per quadrat. At centres B, C and D, four equidistant transects were set out across each block. Five throws with the quadrat were made at random along each transect in each plot, giving 100 points per plot, i.e. 400 points per treatment. Owing to the low plant cover at centre A the number of transects was increased to eight, giving 800 points per treatment.

Botanical assessments were made in 1952, 1954 and 1956.

Herbage analysis. Herbage was taken for analysis from site B only. Samples of *Calluna* from each plot were separated into green shoots and woody material, the former only being analysed. Calcium and phosphorus were determined by the methods of Godden (8) and Yuen and Pollard (22), respectively.

RESULTS

(1) *Soils*

As the values obtained for readily soluble phosphorus were in many cases less than 1 mg./100 g., the following results relate only to the effect of lime treatments on pH and CaO content (Table 3).

Calluna communities

At Glensaugh, the pH and CaO values show a linear relationship with increased dressings of lime in all years. No interaction between lime and phosphate on soil values could be detected. CaO and pH figures at Tulloch show essentially the same effects as at Glensaugh, although the linear relationship is not apparently so marked owing to the negligible effect of the low lime treatment.

Grassland communities

At Huntly a linear relationship between increased lime and soil pH and CaO occurs. Although some significant interactions between the lime and phosphate treatments were detected, they were not consistent.

At Tomdhu the mean values show that the effect of lime on pH and CaO was similar to that at Huntly. At all centres except Tomdhu, CaO values tend to increase with time: the probable reasons for this are dealt with in the discussion.

(2) *Vegetation*

The botanical data refer to the major floristic changes evident by 1956, several minor species of little agronomic significance being grouped together.

TABLE 3. Mean effects of lime treatments on soil pH and CaO values (mg./100 g.) for 1954, 1956 and 1959 (S.E. based on 24 D.F.)

		1954		1956		1959	
		pH	CaO	pH	CaO	pH	CaO
Glensaugh	Ca_0	4·3	70	4·2	90	4·1	90
	Ca_1	4·4	108	4·3	140	4·3	140
	Ca_2	4·8	380	5·1	466	4·9	384
	S.E (±)	0·06	30·1	0·07	25·5	0·05	25·4
Tulloch	Ca_0	4·5	89	4·4	102	4·6	97
	Ca_1	4·5	89	4·5	117	4·6	115
	Ca_2	5·2	249	4·9	227	5·0	224
Huntly	Ca_0	5·2	52	5·2	59	5·3	72
	Ca_1	5·3	59	5·2	73	5·3	94
	Ca_2	5·4	116	5·7	209	6·1	259
	S.E. (±)	0·03	3·6	0·03	10·1	0·04	10·0
Tomdhu	Ca_0	5·3	97	5·2	97	5·3	96
	Ca_1	5·4	118	5·3	119	5·5	101
	Ca_2	5·7	305	5·7	204	5·8	171

PLATE 1. Condition of vegetation at Glensaugh in 1952.

PLATE 2. Condition of vegetation at Tulloch Moor in 1952.

PLATE 3. General view of experimental site at Tulloch in 1956 showing the dominance of *Calluna*. The greater flower abundance on the high phosphate plot to the left of the dotted line is also illustrated.

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PLATE 4. Condition of vegetation on control plot at Tomdhu in 1957 illustrating the dominance of *Nardus stricta* (compare with Plate 5).

PLATE 5. Effect of phosphate in the presence of lime at Tomdhu. Note the abundance of white clover and degeneration of *Nardus*.

TABLE 4. Effect of treatments at Glensaugh on mean percentage bare ground in 1952, 1954 and 1956

Year	Ca_0	Ca_1	Ca_2	P_0	P_1	P_2	Mean
1952	89·4	88·1	87·5	88·5	88·1	88·3	88·3
1954	64·4	46·7	43·0	58·2	49·0	47·2	51·4
1956	37·4	25·1	20·6	32·9	24·8	25·0	27·5

Calluna communities

(1) *Glensaugh*. Table 4 shows a progressive decline in percentage bare ground throughout the experiment which reflects recolonization after burning in 1950.

Both phosphate and lime are significant in stimulating the development of vegetation cover. In the case of lime, the response is highly significant in both 1954 and 1956, the effect of Ca_2 being only slightly greater than Ca_1. The response to phosphate is similar though less marked (5% level) and no significant interactions occur.

Owing to the high proportion of bare ground at Glensaugh, this category was excluded from the botanical analysis, each component or group of species being expressed as a percentage of the total vegetation. The data are presented diagrammatically for all centres in Fig. 1.

Erica cinerea, *Agrostis* spp. and mosses show an overall increase in frequency, while the relative contribution of *Calluna* declines, the mean figures for this species being 45·2% and 31·5%, respectively, for 1952 and 1956.

Both low and high lime depress *Calluna* (1% level), an effect already apparent by 1954. Phosphate has no decisive effect on the frequency of *Calluna*. *Erica* decreases with phosphate (0·1% level) while lime increases it (5% level). The mosses increase linearly with P (5% level) and lime produces a highly significant increase in their contribution. *Agrostis* shows no consistent treatment responses, but the miscellaneous grasses show a positive linear response to lime.

(2) *Tulloch Moor*. At this centre, the treatments were applied six years after burning and, though at a more advanced stage than at Glensaugh, vegetational development went on throughout the experiment. This is reflected by the overall and fairly uniform increase in *Calluna* and general reduction in bare ground, irrespective of treatment (see Fig. 1). The mean values for *Calluna* frequency in 1952 and 1956 are 64% and 80%, respectively. There is slight evidence of an overall increase in grass species, mainly *Festuca ovina* and *Deschampsia flexuosa*, but again no apparent treatment responses.

It is interesting to note that in 1956 and 1957 *Calluna*, on the high phosphate plots, showed a very marked increase in flower abundance (Plate 2). In view of the botanical purity of the vegetation and lack of treatment responses in terms of floristic changes, a useful opportunity was presented to determine the treatment effects on the Ca and P content of the dominant plant. No marked effects were detected at the low rates of lime and phosphate in 1955 and 1956 when sampling was done. Mean figures for the zero and high levels, respectively, for CaO and P_2O_5 were 0·65–0·75 and 0·20–0·26%.

Grassland communities

(1) *Huntly*. Between 1952 and 1956 the principal overall effect is a reduction in *Agrostis* spp. and an increase in the frequency of *Festuca* spp. and *Trifolium repens* (see Fig. 1).

Agrostis frequency shows a highly significant decline with increasing lime. The frequency values for low and high lime are, respectively, 55·1% and 53·1% in 1952 and 37·9% and 27·3% in 1956. *Festuca* shows a very significant increase at the high-lime level. Neither *Agrostis* nor *Festuca* responds to phosphate.

White clover (*T. repens*) shows a very significant increase with increasing phosphate. Lime also gives a significant increase. From the agronomic standpoint the low-lime/high-phosphate treatment produced as good a sward as where high lime had been applied with the same rate of phosphate, and better than high lime in the absence of phosphate.

(2) *Tomdhu*. *Nardus* (Fig. 1) shows a general reduction over the experimental period, the fall increasing with lime and phosphate.

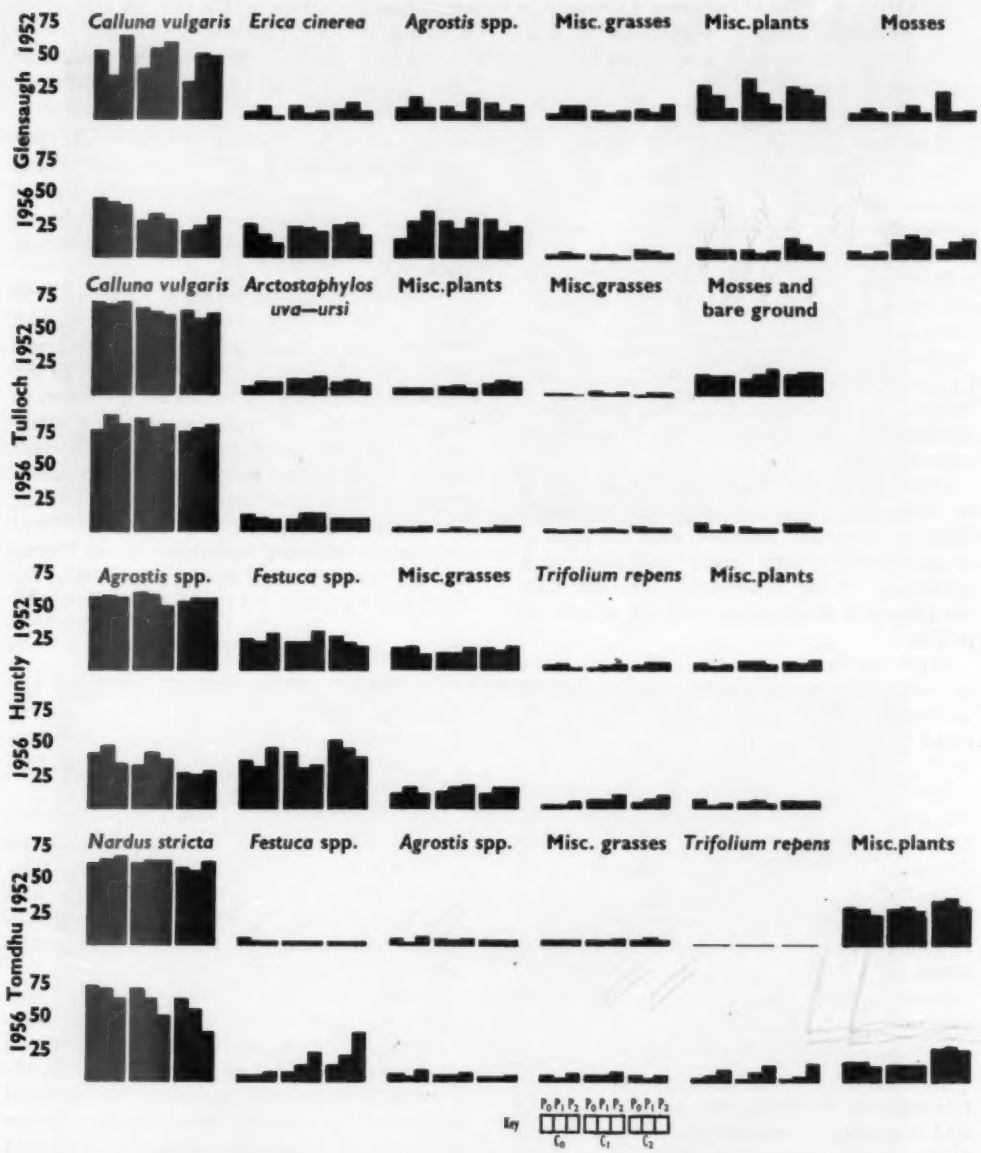

Fig. 1. Response of vegetation to treatments between 1952 and 1956. Histograms show % frequency of sward components.

Festuca spp. show a positive response to increasing lime and phosphate while the contribution of *Agrostis* spp. remains substantially unchanged.

White clover shows a slight response to lime but tends to increase with phosphate at both levels of lime.

DISCUSSION

The effects of the lime treatments on pH and CaO conform with expected results on such soils. Compared with conventional standards for arable soils, the low lime treatments have been inadequate to raise the CaO content to an acceptable level. At the high rate of lime, however, the CaO values are almost representative of those found under improved pasture conditions and approach a level suitable for arable production. Glensaugh is exceptional in this respect owing to the high organic-matter content and buffer capacity of the soil and the CaO values at the high-lime treatments are still below normal standards.

In relation to vegetation responses, however, the low-lime treatment, combined with grazing, has enhanced the agronomic value of the swards at both grassland centres. It is significant that under the prevailing grazing conditions, the high lime, though exerting a much greater effect on soil CaO and pH, did not show a great agronomic advantage over the low lime.

Although considerable residual effects are maintained at the high level of lime, a feature of the soil data is the apparent inconsistency in trends with time. A decline in soil CaO is to be expected, though losses by leaching may be less severe under acid-pasture conditions than under arable cultivation. This tendency is, however, apparent only at Tomdhu. At Glensaugh and Tulloch, the results from year to year are somewhat erratic. This may be attributed to the uneven nature of the ground and consequent redistribution of lime by surface wash causing difficulties in obtaining representative samples. The increase at Huntly between 1954 and 1959, particularly at the high rate of lime, appears to be related to the presence of a surface "mat" which prevented the immediate incorporation of lime with the soil.

The interaction of soil nutrient status and grazing intensity is an important factor in determining floristic balance in pasture. Although applied nutrients may exert a direct deleterious influence on certain species, there is no evidence of an effect of this kind in these experiments. This is of interest in view of the belief sometimes held that the application of lime to Callunetum will kill the heather. These observations have emphasized the importance of the grazing factor in initiating vegetation change, even in Callunetum treated with high rates of lime and phosphate. At Glensaugh, both the stage of development of the community and the grazing intensity were favourable to vegetation response. At Tulloch, neither of these conditions obtained and though the treatments may have imparted a competitive advantage to some subordinate species, the high grazing pressure necessary for its expression was absent. At Glensaugh, lime accelerated recolonization, even at the lower rate, and modified to some extent the species balance. In relation to other species, *Calluna* showed a decrease with time and the decline in its importance with increasing lime was probably related to differential grazing intensity (7).

It is perhaps surprising that the treatments failed to raise the calcium content of edible herbage at Tulloch above that found by Thomas (20) in untreated *Calluna* in Northumberland. A substantial rise in the calcium and phosphorus content of green shoots has been found by Fairbairn (6) in response to lime and phosphate dressings, but the rates employed were much heavier than in the present study.

The initial pH at Huntly was at about the threshold for white clover growth (11) and phosphate produced swards of much improved agronomic value without the heavy application of lime. The high lime, however, did change the sward balance more markedly in favour of *Festuca* spp. A similar change in the balance between *Agrostis* and *Festuca* was found in an earlier series of trials on unfenced plots (13), although under controlled grazing conditions,

especially with applied nitrogen, the balance shifted in favour of *Agrostis*.

At Tomdhu white clover responded more markedly to high phosphate in the presence of lime, an effect no doubt accentuated by the higher grazing intensity and the use of mixed stock (Plate 3). Again, however, the high-lime showed little advantage over the low-lime treatment. The principal change in balance among the grass species was that between *Nardus* and *Festuca*, the latter occuring in greater abundance with increasing phosphate, especially in the presence of lime.

Although the vegetation responses, even at the grassland centres, have not been spectacular, certain treatments have given improvements of a useful order in relation to the original condition of the pasture, while in some cases the lime treatments have left persistent soil effects. The emphasis of the early Welsh work lay largely on showing how one pasture type of low agronomic value could be changed into types resembling much more productive lowland swards. Since this time, however, it has not been sufficiently recognized that the problem of improving fairly extensive tracts of upland pasture, where grazing control and fertilizer maintenance are necessarily of a lower order, does not depend entirely on raising soil fertility to a level required for the best swards. The alternative approach of developing sward types which can be maintained under less intensive conditions of manuring and management has not been fully investigated. The use of comparatively low rates of lime and phosphate for the upgrading of certain hill swards may well be seriously considered, provided a satisfactory measure of stock control can be ensured.

APPENDIX

Soil profile descriptions from the four experimental sites

Site A

Horizon	Depth	
L	0–0·5 in.	Litter.
F	0·5–2·5 in.	Black fibrous raw humus.
H	2·5–3 in.	Black greasy humus with quartz particles.
A_2	3–9 in.	Grey stony fine sandy loam.
B_1		Thin discontinuous iron pan.
B_2	9–19 in.	Orange-brown stony fine sandy loam merging into:—
B_3	19–29 in.	Grey-yellow stony loamy sand, moderately indurated.
C	29 in. +	Thin till derived from quartz-mica schist.

Site B

L		Burnt off.
F	0–0·5 in.	Black raw humus.
H	0·5–1 in.	Black greasy humus.
A_2	1–3 in.	Grey loamy sand.
B_1		Humus iron concentration.
B_2	3–15 in.	Light yellow-brown coarse loamy sand merging into orange-brown sand which becomes paler at depth. Merges into:—
C	15 in.+	Fluvio-glacial sand and gravel.

Site C

L	0–2 in.	Litter and turf interwoven by fine roots.
A_1	2–12 in.	Medium brown silt loam with pronounced pisolitic crumb structure. Sharp change into:-
B_2	12–19 in.	Yellow-brown fine sandy loam merging into:—
B_3	19–36 in.	Grey-brown loamy fine sand with some gravel and moderate induration at 20–24 in. Merges into:—
C	36 in.+	Thin till derived from quartz-mica schist.

Site D

L	0–0·5 in.	Turf.
Ag	0·5–12·5 in.	Dark brown silty loam; ochreous mottling associated with decaying roots. Sharp change into:—
	12·5–18·5 in.	Pinkish micaceous sand (leached).
	18·5 in+	Grey alluvial sand with horizontal bedding.

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THE PRODUCTIVITY OF LAND AND FEED USED FOR LIVESTOCK PRODUCTION IN BRITAIN COMPARED WITH BELGIUM, DENMARK AND THE NETHERLANDS

PART II

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Inter-country differences

We may now summarize the causes of the differences in the number of acre-equivalents of feed required per £1,000 of livestock production (Table 5).

The effects of the variation in feed conversion rates for the grazing livestock, and in the composition of the complex of feed crops used remain to be taken into account.

Feed conversion rate for grazing livestock

Existing data on conversion rates for ruminants are not sufficient for making reasonably accurate estimates which could be put into Table 5. The higher yields per cow obtained in the continental countries are probably associated with lower feed/output ratios. Beef and veal in the continental countries are often by-products of the dairy enterprise, with a preponderance of "young beef" and of cow beef culled from dairy herds. Such a system would probably lead to a better conversion of feed to beef in terms of total tonnage.[10] In the absence of comparable information, the value of beef has been estimated as if it were the same product in each country, which does less than justice to the British feed productivity. The net effect on the feed/output ratios must remain indeterminate until better data are available.

Differences in the composition of feed input[11]

The yield of feed nutrients produced per acre differs with the crop, and the proportion of land under different crops can therefore affect the productivity of the total. Of the four countries studied, Britain has the highest ratio of grassland to arable feed crops, but this should not, of itself, unfavourably affect Britain's area/output ratio for, according to

TABLE 5

	Belgium %	*Denmark* %	*Netherlands* %
Percentage of total difference (between U.K. and each country) which would be eliminated by adopting the continental countries' pattern with regard to*			
Composition of output	1·5	16·5	5·9
Yield of grain	9·7	19·5	12·1
Utilized yield of grass and other bulky foods (based on O.E.E.C. grassland estimates)	23·0	31·7	45·5
Feed conversion rates for pigs and poultry†	5·5	6·0	5·8
All the above factors†	38·4	68·0	65·3

*The individual differences due to the change in each variable were calculated on the assumption that all the other variables remained at U.K. level. The effect of changing them all simultaneously is less than the sum of the separate effects of each because of interaction. If pigmeat had been produced in the U.K. at Danish conversion rates, approximately 605,000 tons of grain would have been saved in 1953 and 1954. At British grain yields, this saving represents approximately 590,000 acres but, with grain yields raised to the Danish level, the saving would have become only 425,000 acres.

†See Part I, Note (8).

both the O.E.E.C. and the Grassland Utilization Committee estimates, British grassland produces a higher yield of nutrients per acre than the grain crops which make up a large proportion of arable feed acres.

The O.E.E.C. figures for grassland probably underestimate the intercountry differences in grass yields; consequently, Table 5 probably underestimates the effect of differences in bulky food yields. Thus, the difference in hay yields between Britain and Denmark is greater than the difference between the O.E.E.C. estimates of the two countries' grass yields.[12] The ratio between nutrient yields of root crops (14, 26) is almost exactly the same as the ratio between those of hay, Denmark's 1·00 to Britain's 0·635. An estimate of the total Danish production of feed nutrients from grass and bulky foods is available in the official statistics, (26) which rely largely on sample surveys of the amount of feed consumed. We may thus assess the probable yields of starch equivalent per acre of British grassland and other bulky foods as 0·635 of the Danish yields.[13]

The Belgian yields of roots and hay (16, 23) can also be compared with the Danish figures. Here the relationship is different, the Belgian yield of nutrients from hay being 0·896 times and from roots 2·143 times the Danish figure.[14] We must now assume that the ratio between the two countries' yield per acre of grassland is the same as that between their hay yields.

Netherlands statistics do not contain sufficient information for making such estimates. However, we may now estimate the yields of starch equivalent of all bulky foods in Belgium, Denmark and Britain, as follows:

Belgium	42·5	cwt.	per acre
Denmark	45·0	,,	,, ,,
U.K.	28·6	,,	,, ,,

The ratios between the Belgian and British, and between the Danish and British yields are higher on this basis than on that of the O.E.E.C. estimates. Consequently, the proportion of the inter-country difference in the area/output ratio which can be explained by the difference in yields of bulky foods is higher than was indicated in Table 5. These alternative estimates of the percentage of the total difference between U.K. and the other countries, which would be eliminated by achieving these countries' yields of grass and other bulky foods, are as follows: 43·1 per cent if Britain achieved Belgian yields (compared with 23·0 per cent shown in Table 5), and 46·6 per cent if Danish yields were achieved (31·7 per cent). The combined effect of the factors becomes 57·3 per cent in the case of Belgium (38·4 per cent) and 79·4 per cent in that of Denmark (68·0 per cent).

We are now able to consider the influence of the composition of feed input on the overall area/output ratio. The comparative yields of the two broad classes of feed are shown below.

	Cwt. starch equivalent per acre		
	Belgium	Denmark	U.K.
Grass and other bulky foods	42·5	45·0	28·6
Grain (average of oats and barley)	15·4	18·7	13·4

On this basis, if Britain were to obtain its 1953–54 quantity of starch equivalent from a feed input in which the share of grassland and other bulky foods were 54 per cent of the total "acre-equivalents", as in Denmark, instead of 65 per cent, the number of acre-equivalents per £1,000 of livestock production would become 37·34 instead of 34·67 (Table 1). This reduction of the proportion of grass and other bulky foods to the Danish level, with other things kept constant, would increase the difference between Britain's and Denmark's area/output ratio by 15·1 per cent.

While this assumes that, in replacing grassland and other bulky foods with grain, each cwt. of starch equivalent in grass and other bulky foods produces as much livestock output as one cwt. of starch equivalent from grain, there is experimental evidence which throws doubt on the one for one substitution ratio (of starch equivalent) and indicates that increasing the proportion of fibrous foods leads to an increasing marginal rate of substitution of grain for fibrous foods (31–35). The effect of this may be shown by assuming that 1·391 lb.[15] starch equivalent in bulky

foods replaces 1½ lb. starch equivalent in concentrates. (This ratio was found at grain input per gallon of milk similar to the U.K. average (32)). The effective yield of starch equivalent per acre of grassland and other bulky foods would then be 30·6 cwt. in Belgium, 32·4 cwt. in Denmark and 20·5 cwt. in Britain. On the basis of these "effective" yields, reducing Britain's proportion of grass and other bulky foods to the Danish level would increase the number of acre-equivalents per £1,000 of livestock production to 36·23. This would mean an 8·8 per cent increase in the difference between the two countries, instead of the 15·1 per cent calculated on the basis of "gross" rather than "effective" yields.

The following inter-country comparison of the ratio between the total quantity of nutrients and the total livestock output, based on these estimates, may be of interest (See *A*, below).

These figures represent the feed/output ratios, and are not, therefore, dependent on yields per acre. Consequently, the relative position of the countries is different from that in Table 1, e.g. Denmark's high yields do not affect her *feed/output* ratio, but they do help to make her *area/output* ratio lower than Belgium's. The comparative position of the three countries is perhaps best shown in the form of index figures, (See *B*, below).

Where yields per acre do not affect the position, Britain's input/output ratio is not so far above the other countries' ratios. However, the figures in the second line probably overestimate the differences in productivity, and those in the third line may be nearest to expressing the actual differences in livestock husbandry alone, when crop yields are left out of account. Because of Britain's lower yields of grass and other bulky foods, the assumption of a greater-than-unity rate of substitution of grain for bulky foods makes only a slight difference to the comparative productivity of feed in the three countries, despite the larger acreage of grassland in Britain.

None the less, better data on the substitution rate of starch equivalent between one feed and another are badly needed for general farm management purposes. Uncertainty as to the marginal substitution rates between grass and other feeds is almost certainly militating against the better use of grassland in Britain.

Contribution of different crops to the value of livestock output

The estimates quoted in the preceding sections suggest that the yield of nutrients per acre is higher from grassland and other bulky foods than from grain. Yet Table 2 shows that more acre-equivalents are required to produce £1,000 worth of livestock output in those enterprises which use an appreciable quantity of grass and other bulky foods than in pig and poultry farming, which rely almost exclusively on grain.

This suggests that an acre of grassland or of other bulky foods, despite its higher nutrient yield, usually contributes less to the value of livestock production than an acre of grain. The cause lies in the relative product prices and feed conversion rates in the different branches of livestock production. For example, it can be estimated that in Britain, one ton of

A	*Cwt. starch equivalent per £1,000 livestock production*		
	Belgium	*Denmark*	*U.K.*
Total starch equivalent	538	560	807
Effective starch equivalent (assuming rate of substitution of grain for bulky foods =1·391)	426	444	626

B	*Belgium*	*Denmark*	*U.K.*
Index of acre-equivalents per £1,000 of livestock production	53·1	49·1	100·0
Index of total starch equivalent per £1,000 of livestock production	66·7	69·4	100·0
Index of effective starch equivalent per £1,000 of livestock production (assuming rate of substitution of grain for bulky foods =1·391)	68·0	70·9	100·0

utilized (effective) starch equivalent produces, on average, about £65 worth of pigmeat, but only between £29 and £36 worth of beef (at 1953 prices) (4, 15) because beef has a lower price and poorer conversion rate.

We may conclude that increasing the share of cereals in the total feed supply is not likely to reduce the overall area/output ratio unless the additional concentrates are fed to pigs and poultry. This would result, however, in changing the "basket of goods" and might lead to practical difficulties.

In Britain the discrepancy between the acre-equivalents required per £1,000 of output for grazing and non-grazing livestock is particularly great (Table 2). Moreover, Table 3 shows that agriculture in Britain is more dependent than in the other three countries on types of livestock for which grass, roots and green crops are the principal keep. Also, the share of grassland and other bulky foods in the total acre-equivalents is greater. It is, therefore, particularly desirable for Britain to increase livestock output per acre of grassland and other bulky foods, by raising the average yield per acre and by improving the feed conversion rates of sheep and cattle. This would enable us to reduce the overall area/output ratio without altering the "basket of goods", for the additional fodder could be used to replace some of the imported concentrates now fed to dairy cattle, rather than to produce more milk, beef or sheep products.[16]

Production net of imported feed

So far both home-grown and imported feedingstuffs have been treated together in considering the relationship between feed and output: in fact their use cannot be differentiated. In estimating the area-equivalent of imports, however, the grain yields of the individual countries have been used. This has the effect of showing a smaller area-equivalent per ton of imports for the three foreign countries than for Britain, whose grain yields are relatively low. Had the same conversion factor for imports been used for all countries, however, it would only have affected the overall ratios fractionally.

Another way of attempting to deal with this difficulty is to calculate production net of imported feedingstuffs and to relate this to the area of home-grown feed used in each country. The productivity of "home feed acres" in each country on this basis is given in Table 6.

In most cases, this productivity of "home feed area" is higher than the overall productivity shown in Table 1, (i.e. the area/output ratio is lower). This apparent improvement is due to the fact that, in the countries concerned (i.e. with output valued at British prices, in Belgium, the Netherlands and Denmark; and with output valued at Danish prices, in Belgium and the Netherlands) the overall output per feed-acre is greater than the cost per acre-equivalent of imported feed. In calculating the "net" output we have deducted from the total output only the cost of imported feed, and not the output attributable to it. Consequently, this calculation has led to a smaller decrease in output than in acreage.[17] The reverse is true in Britain because of the low

TABLE 6. Acre-equivalents of home-grown feed per £1,000 of livestock production net of imported feed*

	Belgium	Denmark	Netherlands	U.K.
1. *With production valued at 1953 British prices:*		Acre-equivalents		
Grass	8·98	6·82	10·31	25·22
Other bulky foods	1·96	3·09	1·12	2·20
Concentrates (including grain)	5·05	6·59	3·54	7·44
Total	15·99	16·50	14·97	34·86
2. *With production valued at 1953 Danish prices:* (In £ at current rate of exchange)				
Grass	13·97	10·44	16·87	36·97
Other bulky foods	3·06	4·72	1·83	3·23
Concentrates (including grain)	7·85	10·09	5·80	10·90
Total	24·88	25·25	24·50	51·10

*Wherever possible, imports were valued at 1953 U.K. import prices calculated from Ref. 22 but in a few cases Belgian or Dutch prices had to be used (Ref. 23 and 24).

livestock output per acre; and—with the output valued at Danish prices—in Denmark, because of the high cost per acre-equivalent of imports, due to the high grain yields assumed in calculating the equivalent area of imported feedingstuffs.

These discrepancies would be unlikely to occur if the actual output from imported feed were known, for the imported feed is used largely in pigmeat and egg production, where productivity of feed is higher than the overall average (compare Table 2). Consequently, if we could arrive at the "net" output by deducting from total production the actual output obtained from imported feed, instead of the cost of this feed, the resulting productivity of 'home feed area' would be consistently lower than the overall productivity of feed. Since the nature of the available data makes such a calculation impossible the results given in Table 6 are not comparable with those in Table 1. They cannot be regarded as physical input/output relationships, but only as a tentative approach to the problem of productivity of home feed area.

Conclusions and general considerations

Because of its relatively low average grass and crop yields per acre and less satisfactory feed conversion rates, as well as a relatively large share of lamb, mutton and mature beef in the total output, Britain uses approximately twice as much land (or acre-equivalent of feed) per unit of livestock production as do Belgium, Denmark and the Netherlands. In other words, the gross livestock output per acre of feed in Britain is only half of that in the other three countries. But is the output per acre as important to the British farmer as it is to his Belgian, Danish and Dutch neighbours? From the point of view of many British farmers, the answer is "no". In the U.K., 60 per cent of agricultural land is farmed in units of over 50 hectares (123·5 acres), in Denmark 20 per cent and in Belgium and the Netherlands only 10 per cent (36). Other things being equal, the larger the farm, the smaller is the output per acre necessary for achieving a reasonable income. In the U.K. there are only 37·8 people engaged in agricultural occupations to each 1,000 acres of agricultural land as against 98·3 in Belgium, 67·3 in Denmark and 130·3 in the Netherlands,[18] so that a lower output per acre suffices them.

In comparison with the three continental countries, Britain's more extensive use of land can be partly explained by its abundance in relation to labour; and their costs encourage the substitution of land for labour in Britain to a greater extent than in Belgium or the Netherlands. (See Appendix Table F).

It would be interesting to know whether in fact Britain uses labour more economically in livestock production than Belgium, Denmark and the Netherlands, but this would require a separate investigation. Meanwhile, it is possible to estimate approximately the number of persons in agricultural occupations per £1,000 of the whole agricultural production valued at British prices.[19] It then appears that Belgium had 1·15 persons per £1,000 of output, Denmark 1·09 persons, the Netherlands 1·45, and the U.K. 0·99. Since livestock accounts for the major part of agricultural output (70 per cent in Belgium, 84 per cent in Denmark, 68 per cent in the Netherlands, and 71 per cent in the U.K.—with output valued at British prices throughout), it seems likely that in livestock production, as in the total agricultural production, Britain uses less labour in relation to output than the three foreign countries. However, since these figures do not give any indication of the hours worked, and since the output calculation is only approximate, this impression should not be treated as in any way an accurate estimate.

If these figures reflect the number of man-years used to produce £1,000 of livestock output, we can calculate the land/labour ratio in livestock production, giving 11·9 acre equivalents per man-year in Belgium, 14·1 in Denmark, 8·8 in the Netherlands and 28·9 in the U.K.[20] This suggests that land for livestock feeding is used much more lavishly in Britain than in the three foreign countries.

Crop and grass yields are the most direct indicators of intensity of land use, and we have

pointed out that U.K. yields are, in general, lower than those of the other countries studied. Partly this may be due to the less favourable climate, but to a certain extent it is a reflection of the difference in the fertilizer usage. For example, the indices of total fertilizer consumption per acre of agricultural land (excluding rough grazings) in 1952–53 (39) are: Netherlands 100, Belgium 95, Denmark 58, U.K. 37. It is also interesting to compare the 76 lb. of nitrogen per acre of grassland, estimated to be the current average application in the Netherlands (40) with the 15 lb. per acre of a recent British survey (41).

Some British farmers, with bigger farms at their disposal, may not be so anxious to achieve the maximum output from their land. However, extra home-grown feed from increased yields could be used to replace purchased feedingstuffs; and this may greatly reduce the cost per unit of feed, and therefore per unit of livestock production, especially when the increase comes from grassland.[21] Similarly, an improvement in feed conversion rates can reduce the cost of feed per unit of product and need not be accompanied by an increase in the volume of production.

Many British farmers do achieve high yields of home-grown feed, mainly through good grassland management and a high manurial level. Thus, in the recent milk production survey carried out by Manchester University economists (43), the "high output" farms, which had 55 per cent of their grassland in leys and used £4·7 worth of fertilizers per acre of grass and kale, obtained 17·2 cwt. of starch equivalent per acre of grass and kale and had a total feed cost of less than 1s. 4d. per gallon of milk produced. When these figures are compared with those from "low output" farms (22 per cent of leys. £1·6 worth of fertilizers and only 8·8 cwt. of starch equivalent, with total feed cost of over 1s. 8½d. per gallon), they suggest that there is plenty of scope for raising the average yields of fodder in Britain, thus reducing the unit costs of production.

The scope for cost reduction by improving feed conversion rates is probably not so great, but certain valuable suggestions with regard to pig production are contained in a comparative study published a few years ago (4), while a recent Manchester report (44) shows that certain British pig producers achieve low unit costs and high profits through a good conversion rate and quick turnover. More research and more application of existing knowledge is needed if we are to bring the average British feed conversion rates up to the higher continental standards.

To British farmers, individually, keeping livestock production costs down is not so vital as in Belgium, Denmark or the Netherlands, for—in terms of livestock product prices—land (except in comparison with Denmark) and labour are cheaper in this country (see Appendix Table F). But this situation exists only because, through the agricultural support system, British product prices have been kept at a higher level than that prevailing in the world market. It is by no means certain that British agriculture can maintain this advantage indefinitely. Already, the import concessions made to Danish bacon producers are a reminder that some British agricultural commodities may be facing increased competition from lower-priced foreign products. This points to the possibility of costs becoming more important to the British farmer than they have been in the past two decades.

To the farmer, land is a cost of production. Reducing the area of land needed to produce a given value of livestock output would lower the British farmer's total cost of production if it could be achieved without incurring a commensurate increase in other costs. It is in the yield of bulky foods, particularly grass, and in the efficiency of converting these to livestock products that Britain would appear to lag furthest behind its three continental neighbours. Much work remains to be done in finding out which methods of increasing output of home-grown feed would be most generally acceptable, and how the different feed crops can be combined to the best advantage, but such research would make a valuable contribution to cost reduction in British agriculture and to the improvement of farmers' incomes.

NOTES

(10) Since writing the above, the author has received from Dr. R. O'Connor, Central Statistics Office, Dublin, the following estimates based on Sheehy's Animal Nutrition (30): lb. starch equivalent required per lb. liveweight gain: beef animals killed at 17 months: 3·6; beef animals killed at 30 months: 4·5.

(11) This section owes much to the suggestions and comments made by Professor Glenn L. Johnson, Michigan State University.

(12) Compare O.E.E.C. grass yield figures (U.K. 1,200 fodder units per acre, Denmark 1,600 fodder units per acre) with the official estimates of hay yields (in cwt. per acre):

	1953		1954	
	U.K.	*Denmark*	*U.K.*	*Denmark*
Temporary grass	31·9	54·2	30·0	45·3
Permanent grass	23·5	37·4	22·6	32·4

Sources: Ref. 13 and 14.

The gap between the two countries is larger here than in the O.E.E.C. grassland estimates. However, the differences between the two countries might conceivably be smaller if the aftermath grazing were taken into account.

(13) This ratio may, in fact, be too high, for much of the British "other bulky foods" acreage consists of kale for folding which supplies less starch equivalent per acre than the intensively grown roots of the continental countries.

(14) The high nutrient yield per acre of roots in Belgium is due to the high yield of fodder beet, the main fodder root crop in that country.

(15) This conversion factor is, of course, arbitrary, and has been chosen solely for the purpose of illustration. The appropriate factor is likely to be lower for pasture and succulent fodders, but may be expected to increase as the proportion of bulky foods in the diet rises above the relatively low level of the Iowa trials (31, 32).

(16) This problem is fully discussed in the report of the Grassland Utilization Committee (12).

(17) The following figures show how the costs per acre-equivalent of imported feed compare with average livestock output per acre-equivalent of all feed.

	Belgium	*Denmark*	*Netherlands*	*U.K.*
Cost per acre-equivalent of imported feed	£30·4	42·0	36·1	29·6
Livestock production per acre equiv. of all feed: (average 1953–54)				
(a) at British prices	£54·3	58·7	59·3	28·8
(b) at Danish prices	£37·7	39·8	39·7	21·3

The influence of these results on the productivity of "home feed area" can be proved algebraically. Let a be the total acre-equivalents of all feed: b total livestock production; c acre-equivalents of imported feed, and d, cost of imported feed. Then $\frac{a}{b}$ = overall area/output ratio (as in Table 1), and $\frac{a-c}{b-d}$ = "home feed area"/output ratio (as in Table 6). For $\frac{a-c}{b-d}$ to be *less* than $\frac{a}{b}$, $\frac{c}{a}$ must be greater than $\frac{d}{b}$. By multiplying both sides of this inequality $\left(\frac{c}{a} > \frac{d}{b}\right)$ by $\frac{b}{c}$, we obtain $\frac{b}{a} > \frac{d}{c}$, i.e. production per acre-equivalent of all feed must be greater than cost per acre-equivalent of imported feed. Naturally the reverse must be true for $\frac{a-c}{b-d}$ to be *greater* than $\frac{a}{b}$.

(18) Calculated from Ref. 10 on the basis of the 1954 area, adjusted for hills and rough grazings in the case of the U.K. The number of persons relates to the year 1947 for Belgium and the Netherlands, 1950 for Denmark and 1951 for the U.K.

(19) The number of persons is taken from Ref. 10 and relates to the year 1947 for Belgium and the Netherlands, 1950 for Denmark and 1951 for the U.K. The U.K. production is that shown for 1953/54 in Ref. 37. The foreign countries' 1953 crop output given in Ref. 23 and 37 has been re-valued according to price indices given by Nash (Ref. 38), and their livestock production is that given for 1953 in Appendix Table C of the present paper.

(20) Imported feed is excluded from this calculation, which is very approximate.

(21) For example, in an investigation conducted by the writer on a sample of farms in 1954 (42), the cost per ton of starch equivalent obtained from grassland varied from £8 17s. to £19 12s., whereas the estimated average cost of winter feed was £47 12s. per ton of starch equivalent. The Grassland Committee's report (Ref. 12) gives the cost of production per ton of starch equivalent in 1956/7 as £12 6s. for for grazing, compared with £25 8s. for oats and £46 2s. for dairy cake. For a detailed discussion of the economic advantages of a high feed output per acre of grass and kale, see Ref. 43 pp. 11–20 and Ref. 12 pp. 19–22.

APPENDIX TABLE F. Relationship between agricultural wages, land values and livestock product prices (1953/54)

		Belgium	Denmark	Netherlands	U.K.
1. *Average values*					
Annual wage of adult farm workers	(£)	379	316	326	382
Annual rent per 100 acres of agricultural land	(£)	622	no data	458	214
Price per acre of agricultural land	(£)	326	66	123	106
2. Indices (U.K. = 100)					
Ratio of rent to wages		293	no data	251	100
Ratio of land price to wages		312	75	137	100
Tons of livestock products, at each country's 1953 prices, required to cover the cost of					
(a) annual wage		134	130	156	100
(b) rent of 100 acres		394	no data	391	100
(c) price of one acre		418	97	213	100

Sources: Ref. 10, 23, 24, 17, 18, 26, 45–47.

Notes: The estimates of rent and price of land in the U.K. are based on data for England and Wales, with the acreage adjusted for hills and rough grazings by the method explained in Appendix 1.
In estimating the price of land in Denmark, one hartkorn tongue was taken as equal to 24·7 acres. (Ref. 9).
Wages quoted are average earnings, *not* statutory wages.
Belgian, Danish and Dutch money values are given in £ at current exchange rates.

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THE RELATIVE PALATABILITY OF VARIOUS VARIETIES OF WEEPING LOVEGRASS (*ERAGROSTIS CURVULA* (SCHRAD) NEES)

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It has been found for pasture purposes that the numerous varieties belonging to the species *Eragrostis curvula* can be grouped into types for which the names curvula, robusta blue, robusta green, robusta intermediate and chloromelas are proposed.

The relative palatability of 20 varieties of *E. curvula*, and 1 variety of *E. plana*, *Chloris gayana* and *Digitaria smutsii* were compared with one another. *Chloris* and *Digitaria* were found to be the most palatable. Of the *Eragrostis* varieties studied, the robusta green, robusta intermediate and robusta blue were the most palatable, chloromelas varieties and *E. plana* being intermediate and the curvula varieties the least palatable.

The grasses with the highest phosphate and potash contents were also those most acceptable to livestock. Results obtained from analyses suggested that crude fibre had little bearing on palatability.

The more acceptable grasses were also the more succulent.

No relationship between leaf structure and livestock preference could be demonstrated.

INTRODUCTION

For maximum economical production of livestock products from grass, the herbage must not only have a high nutritive value, but also be acceptable to stock.

Eragrostis curvula† is a perennial bunch grass occuring widely in permanent and reseeded pastures in South Africa. Certain observations as to the palatability of *Eragrostis* species and varieties have been made and reported by several investigators. Crider (1), working with *E. curvula*, *E. chloromelas* and *E. lehmanniana*, found that new growth was readily grazed when soft and tender. At this period the nutritive value was shown to be at its highest. Davidson (3) observed that Hereford heifers given a choice of *E. curvula* varieties preferred certain ones amongst them, when allowed to graze at will on adjacent pastures of these grasses. However, no obvious correlation between the palatability of these varieties and their carbohydrate or total silica content could be found by Gafin (4). In other analyses no significant differences between the fibre content of *E. curvula* varieties could be shown (Poultney (7)).

In order to verify previous observations on differences in palatability of the various types of *Eragrostis curvula*, this investigation was carried out; certain factors possibly responsible for the differences were also studied.

MATERIALS AND METHODS

The experiment was sown in broadcast stands in February 1956, and the layout consisted of a randomized block with 3 replicates. In each block there were 20 varieties of *Eragrostis curvula* and one variety each of *E. plana*, *Digitaria smutsii* and *Chloris gayana*.

After a careful study of the varieties known collectively under the name of *Eragrostis curvula*, it was found possible to group these under 5 main types to which the names curvula, chloromelas, robusta blue, robusta intermediate and robusta green were assigned. This classification was based primarily on such characters as leaf morphology and colour, inflorescence size and general growth habit. The results of further studies of such characters as anatomy, cytology, fertilizer response, hay and nutrient yields, weed encroachment etc., tend also to support this classification (5).

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†The taxonomy of the genus *Eragrostis* has been revised and the species *Eragrostis curvula* now includes varieties previously known as *E. chloromelas* and *E. robusta*.

The 20 *E. curvula* varieties* were made up of 5 curvula type, 5 chloromelas, 5 robusta blue, 3 robusta intermediate and 2 robusta green varieties.

Plots 20×40 ft. were sub-divided into 3 sub-plots. To these sub-plots the following fertilizer treatments were applied:

Control, no fertilizer.

P_1N_1, fertilized each season with 325 lb. superphosphate per morgen† plus 100 lb. N per morgen as ammonium nitrate.

P_4N_4, fertilized each season with 1300 lb. superphosphate per morgen plus 400 lb. N per morgen.

The palatability trial was carried out on the 4, 6 and 9 December 1957. Earlier in the 1957–8 season, the plots had received two-thirds of their fertilizer dressings and had been cut once on the 22 October 1957. By the start of the trial (45 days after cutting) the grasses were all at the ear-emergence stage.

For this trial the 3 blocks (each containing 23 plots) were fenced off. At 8.30 a.m. on the 4 December 1957 eight cows, previously grazed together, were placed in the first block. The animals had received no feed for the previous 14 hours. They were slowly herded up and down the block for 30 minutes, being allowed time to pause and eat. After this introductory period, the animals were herded to the centre of the block and then allowed to roam at will. The number of minutes spent grazing by each cow (cattle-minutes) and observations of the position of the cows every 5 minutes (cattle-periods) were recorded. At 1 p.m. the animals were removed from the experiment, watered and returned at 1.45 p.m. After another introductory period of 15 minutes, recording was resumed. At 6 p.m. the animals were removed from the plots which were then inspected and rated to assess the degree to which they had been grazed. During the day grazing behaviour was noted. This procedure was repeated for the two other blocks on the 6 and 9 December 1957.

RESULTS

1. *Field observations.* The observations in cattle-minutes, cattle-periods and the observed ratings made at the end of the day, are presented in Table 1.

The final rating was a mean of those obtained from the number of minutes spent grazing by the 8 cows, and the degree to which each plot had been grazed. Cattle-periods were not used in the determination of the final palatability rating, although they are included in Table 1, so that the accuracy and value of this method of determining relative palatability may be assessed. It was further observed that proximity of either a *Digitaria smutsii* or a *Chloris gayana* plot to an *Eragrostis* plot was inclined to exaggerate the preference of the animals for the last.

Heavily fertilized *Eragrostis* plots were preferred to those moderately fertilized, while the control plots were virtually ungrazed. The animals grazed *Digitaria* and *Chloris* at all fertility levels, *Chloris* being preferred. Of the *Eragrostis* varieties, robusta green, robusta intermediate and robusta blue were the most palatable, the curvula varieties were the least and the chloromelas varieties and *E. plana* were intermediate in livestock preference. No variety, not even the most palatable, was grazed for more than a few minutes at a time.

Assessments of the relative palatability of the varieties by observing the positions of animals every 5 minutes, were found in most cases to agree with those made by observing them continuously. Fairly close agreement was also found between those made by observing the pastures before and after grazing, and those made by recording cattle-minutes in each plot.

2. *Phosphate and potash percentages.* Analyses of the phosphate and potash contents in the herbage of *E. curvula* varieties have repeatedly shown the curvula varieties to be low in these elements (5). Phosphate and potash percentages on the 6 April 1958 are

*The reference numbers of the varieties used throughout this paper are the Frankenwald Field Research Station Accession numbers.

†1 morgen = 2·19 acres.

TABLE 1. Relative palatability observations

Type	Variety No.	Cattle minutes: Total grazing time over 3 days (mins.)	Rating	Cattle-periods: Total cattle periods over 2 days	Rating	Observed rating (after grazing): P_4N_4 1–12	P_1N_1 1–12	O 1–12	Total 1–12	Rating	Final Rating
Robusta green	99	428	3	63	5	12	8	1	21	3	3**
	133	300	9	54	6	10	5	½	15½	13	10
Robusta intermediate	104	259	14	41	13	10	3	½	13½	16	14*
	11	302	8	51	7	11½	5	¾	17½	9	9
	131	348	5	67	4	11	5	1	17	11	8
Robusta blue	98	428	3	72	3	10½	5¼	¼	16¼	10	5*
	137	258	15	39	15	11½	5	1	17½	7	10
	90	292	10	47	8	11	6	1	18	5	7
	4	169	23	35	18	7	3	½	10½	20	22
	13	312	7	44	10	10½	7	1	18½	4	4
Chloromelas	3	251	16	38	16	10	4	¾	14¾	14	14**
	81	211	20	25	22	11	5	1	17	11	16
	88	315	6	37	17	11½	5	1	17½	7	5
	79	221	18	46	9	11	6	1	18	5	12*
	7	231	17	44	10	10	3½	1	14½	15	18
Curvula	9	273	11	41	13	7	2	0	9	22	19***
	10	219	19	29	20	6½	1½	0	8	23	21
	87	203	21	26	21	8	3	0	11	18	20
	91	199	22	25	22	7	3	0	10	21	22
	12	261	13	42	12	7½	3	½	11	18	16*
E. plana Northam	5	272	12	32	19	8½	3	0	11½	17	13*
Digitaria smutsii		674	2	87	2	12	12	9	33	1	1
Chloris gayana		1119	1	174	1	12	11	8	31	2	1

*Denotes number of times variety was adjacent to a *Chloris* or *Digitaria* plot.

TABLE 2. Percentage phosphate and potash of P_4N_4 herbage on the 6 December 1957

Percentage phosphate			Percentage potash		
Species and variety no.		$\%P_2O_5$	Species and variety No.		$\%K_2O$
Chloris gayana		0·62	*Chloris gayana*		2·15
137	*E. curvula*	0·57	11	*E. curvula*	2·00
9	,,	0·53	131	,,	1·95
90	,,	0·52	79	,,	1·92
131	,,	0·51	4	,,	1·82
99	,,	0·51	3	,,	1·77
11	,,	0·51	13	,,	1·74
13	,,	0·50	5	,,	1·74
79	,,	0·50	88	,,	1·74
7	,,	0·50	90	,,	1·73
133	,,	0·49	137	,,	1·72
Digitaria smutsii		0·49	81	,,	1·68
81	*E. curvula*	0·49	9	,,	1·66
88	,,	0·47	7	,,	1·62
4	,,	0·47	98	,,	1·59
98	,,	0·47	104	,,	1·59
3	,,	0·46	99	,,	1·57
104	,,	0·46	133	,,	1·56
5	*E. plana*	0·45	*Digitaria smutsii*		1·56
12	*E. curvula*	0·44	87	*E. curvula*	1·50
91	,,	0·42	12	,,	1·50
87	,,	0·42	91	,,	1·42
10	,,	0·42	10	,,	1·35

presented in Table 2. When this table is compared with the palatability ratings in Table 1, it will be noted that of the 12 varieties with the highest phosphate content, 10 were also the grasses which were among the 12 most palatable. Of the 12 grasses with the highest potash content, 8 were among the 12 varieties which were the most palatable.

Plice (6) found that the most palatable plants had the highest content of sugar and phosphate. Sugar production is dependent on phosphate content and although no determinations of sugar were made in this experiment, the high phosphate contents may indicate high sugar content. The latter may have been the factor responsible for the preferences observed.

3. *Percentage of crude fibre.* The crude-fibre percentages of *Chloris gayana*, *Digitaria smutsii*, *Eragrostis plana* and a number of varieties of *E. curvula*, were determined for 141-day-old herbage cut on the 12 March 1958. See Table 3. The determinations showed that the fibre contents were similar and little, if at all, affected by fertilizer treatment. Poultney (1952) found also that there was little variation in the fibre contents of a number of *Eragrostis* varieties investigated.

These results suggest that the crude-fibre content was not an important factor influencing palatability in the species studied.

4. *Moisture determinations.* The moisture percentages of *Chloris gayana*, *Digitaria smutsii*, *Eragrostis plana* and a number of *E. curvula* varieties were determined on the 12 March 1958. See Table 4. In general the moisture content of the lightly fertilized grass plots was higher than unfertilized plots, while the heavily fertilized grass had the highest moisture percentage.

The higher moisture percentages resulting from increasing fertilizer application might have influenced the palatability of the herbage. The relative moisture contents of the *Digitaria*,

TABLE 3. Crude-fibre percentage of herbage cut on 12-3-58

Type	Variety No.	O	P_2N_1	P_4N_4
Robusta green	133			38·5%
Robusta intermediate	131			36·7%
Robusta blue	90	34·6%		
	98	35·8%		
	11		36·8%	
	137			37·5%
Chloromelas	81	36·5%		
	3		37·0%	
Curvula	91	36·0%		
	12		35·4%	
E. plana northam	5	39·9%		
Digitaria smutsii		34·9%		
Chloris gayana			37·8%	

TABLE 4. Percentage moisture of herbage cut on the 12-3-58

Type	Variety No.	O	P_1N_1	P_4N_4	Mean
Robusta green	99	42·0	41·3	55·9	
	133	39·3	47·4	53·7	
Mean		40·7	44·4	54·8	46·6
Robusta intermediate	104	48·4	48·2	56·6	
	11	45·8	50·8	60·5	
	131	46·8	51·6	56·1	
Mean		47·0	50·2	57·7	51·6
Robusta blue	98	51·3	53·7	55·8	
	137	44·2	48·9	70·2	
	90	50·6	46·5	57·1	
	4	51·5	50·2	57·2	
	13	45·3	48·3	58·1	
Mean		48·6	49·5	59·7	52·6
Chloromelas	3	45·2	47·1	56·9	
	81	39·0	45·3	55·4	
	88	45·9	44·0	56·6	
	79	40·7	43·7	55·3	
	7	40·4	46·5	59·9	
Mean		42·2	45·3	56·8	48·1
Curvula	9	41·0	46·6	51·4	
	10	51·4	39·9	50·3	
	87	43·4	43·7	51·4	
	91	38·5	39·7	51·2	
	12	45·2	40·0	52·1	
Mean		43·9	42·0	51·3	45·7
E. plana northam	5	41·9	38·0	62·2	47·4
Digitaria smutsii		54·3	48·2	52·7	51·7
Chloris gayana		50·3	63·6	55·4	56·4
Mean total		45·3	46·7	56·2	

Chloris, robusta blue and robusta intermediate types were all higher than the curvula and, to a lesser extent, than the chloromelas types. The moisture content of the palatable robusta green was not the highest recorded, although it was higher than that of the less palatable curvula type. Small differences in moisture content may affect the palatability of these varieties.

5. *Microscopic investigations of leaf structure.* The leaf anatomy of the *Eragrostis curvula* varieties, *E. plana* and *Chloris gayana* was studied in order to determine whether relative palatability was correlated with leaf structure. The leaf anatomy of the *E. curvula* varieties was found to be very similar and no differences in structure likely to account for the trends in livestock preference could be demonstrated. *Chloris gayana* appeared to contain less fibres, but these observations were not borne out by chemical analysis.

DISCUSSION

The conflicting views of the ecologist, agriculturist, taxonomist and commercial seed producer on the nature, merit and importance of the different morphological types of *Eragrostis curvula* have resulted in confusion. At present in South Africa most research work carried out on *Eragrostis curvula* has been conducted on one variety, namely the Ermelo, or Tanganyika, variety. Since no intensive investigation of the other varieties is being undertaken elsewhere, the behaviour of *E. curvula* as a ley grass is judged on the performance of this one variety: the present investigation shows that it is the least palatable of all the varieties tested.

In reseeded *Eragrostis* pastures differences in palatability may not be of importance where animals are confined to one variety only. Animals which come from more palatable pastures may, however, be adversely influenced

by the relatively low palatability of *Eragrostis* and in permanent pastures the differences between varieties of *E. curvula* result in selective grazing. One danger inherent in investigations of this type is the fact that small differences in palatability between certain herbages are often magnified when they are compared with each other.

The relationship of palatability to nutritive value has not been fully established. Herbage of low palatability may reduce the production of swards because not enough is eaten. Animals have, however, been observed (Davidson (2)) to be capable of making high liveweight gains on some relative unpalatable forage, e.g. *E. curvula* No. 91 (curvula type).

It is interesting to note that while the curvula type is characterized by long narrow bright green leaves and a predominance of leaf over stalk, the robusta types are generally coarse and stalky and with broad blue-green leaves. In the absence of palatability tests, the appearance would suggest, wrongly, that the curvula type would be the more acceptable to livestock.

In conclusion it may be said that the curvula type, this being the only one of which seed is available commercially, cannot be recommended for areas where a low level of fertility is maintained on poor soil. This applies particularly where intensive grazing management is not practised and it is suggested that under these conditions a robusta or chloromelas type should be used. Where intensive grazing is practised the difficulties associated with the management of the curvula-type pastures are less significant because the younger forage is more palatable.

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THE EFFECT OF THE TIMING OF AMMONIUM NITRATE DRESSINGS ON THE HEADING OF S48 TIMOTHY (*PHLEUM PRATENSE* L.)

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The response of single plants of Aberystwyth S48 timothy (*Phleum pratense* L.) to increasing rates of ammonium nitrate applied in the spring and autumn is described.

All spring treatments markedly increased the number of heads, as well as the total head-length per plant, but autumn dressings had no significant effect. Percentage head-length distribution was also greatly influenced by applications of nitrogenous fertilizer in the spring. Each higher rate of application gave a proportionate increase in the number of heads over 9 cm. in length, and a corresponding reduction in the frequency of those of 4 cm. or less. There was a positive correlation between head-length and number of florets per unit length.

The results are discussed in terms of their relationship to current practices in managing timothy crops for seed.

INTRODUCTION

Previous work on problems of harvesting timothy has shown that evenness of ripening is associated with the duration of inflorescence or head emergence, and also that seed yield is closely correlated with total head-length. It was established that seed set per head was similarly related to head-length, shorter heads bearing less seed per unit length than longer ones (6). Any factor, therefore, which tends to increase the percentage of small heads in a crop could have a doubly deleterious effect by reducing seed yield and increasing the range of ripeness.

Langer (4) demonstrated that nitrogen level profoundly affects the rate of tillering in S48 timothy, and that the size of head depends upon the date of origin of the tiller bearing it (Langer, 3). It was suggested, therefore, that the timing of nitrogenous manuring might be used to influence the frequency of small heads, and that some measure of control could be achieved by careful manipulation of spring and autumn dressings (6).

The studies here described were initiated to test these contentions.

MATERIALS AND METHODS

Two experiments were set up, using clonal material of Aberystwyth S48 timothy (*Phleum pratense* L.) planted as 5-tiller units into pots containing a medium loam of pH 7·2 in August 1959 and August 1960. The pots remained outdoors and received supplementary watering only during periods of drought. Nitrogen was applied as ammonium nitrate (35% N) and conversion to equivalent rates of nitro-chalk (15·5% N) can be obtained by multiplying by a factor of 2·26.

Experiment 1. To study the effect of varying rates of ammonium nitrate applied in September and March.

This was laid down as a $5\times5\times5$ split-plot Latin square with 0, 2, 4, 6 and 8 cwt./acre ammonium nitrate applied to the whole plots in September 1959 and to the sub-plots only in March 1960.

Experiment 2. To compare the effect on head production of ammonium nitrate applied at 4 cwt./acre in September 1959 or March 1960, and as a split dressing of 2 cwt./acre in September 1959 and 2 cwt./acre in March 1960. A 4×10 randomized-block design was used.

In each experiment the plants were harvested shortly after cessation of head emergence and the heads were separated according to length into the following groups: $<4{\cdot}0$ cm., 4·1–6·5 cm., 6·6–8·9 cm., $>9{\cdot}0$ cm.

The effects of the various treatments on

potential seed yield were studied by observing the changes in the distribution of the total head-length per plant amongst the 4 groups. Previous work (6) has shown the correlation coefficient for the relationship between total head-length per plant and seed yield per plant in S48 to be, r=+0·861, P=0·05.

Emergence date was defined as the date on which the tip of the second head emerged from the covering leaf sheath.

RESULTS

The significant effects of nitrogenous manuring in spring upon emergence date were recorded in both experiments. It was noted that the heavier the application, the earlier was the emergence date. As far as could be detected the autumn dressings did not advance the date of emergence.

TABLE 1. Relation between date of head emergence and size of spring nitrogen dressing

Ammonium nitrate (cwt./acre)	Mean emergence date
0	8/7
2	4/7
4	2/7
6	30/6
8	28/6
LSD (P =0·05)	1·4 days
LSD (P =0·01)	1·9 days

There was no significant interaction in terms of emergence date between spring and autumn treatments. The number of heads produced per plant and the total head-length per plant showed marked responses to the application of nitrogen in spring (Table 2).

Both these quantitative responses show a tendency to increase with the larger amounts of nitrogen applied in autumn, but only in one instance could significance be established, and even in this case the response was very small in comparison to that obtained with spring treatments.

The degree of replication available for autumn treatments, although sufficient to detect reasonable differences, obviously lacks precision in dealing with the very small differences encountered. It seems that little is to be gained in terms of increase in head-number even from very large dressings of nitrogenous manure applied in the autumn.

The interactions of autumn and spring applications of ammonium nitrate were non-significant for each set of data.

Autumn manuring applied at more than 4 cwt./acre would appear to give little further response in terms of head-number, which suggests that tillering was limited by low temperatures before the full potential of these dressings could be utilized.

It is possible that a greater response would have been obtained if the nitrogen had been applied about 3 weeks earlier, at a time which coincided with the normal cessation of harvesting timothy seed-crops. It would still be doubtful, however, if the response would amount to a significant fraction of that obtained from even the lowest spring dosage.

A close study of the response to spring nitrogen shows that a dressing of 8 cwt./acre gives a fivefold increase in the total head-length per plant, but only trebles the number of inflorescences produced. This is due to differences in distribution of the total head-length within the head population.

It can be seen that ammonium nitrate

TABLE 2. Increase in number of heads and in total head-length per plant in response to spring and autumn nitrogen dressings

Ammonium nitrate (cwt./acre)	Mean heads per plant		Total head-length per plant (cm.)	
	Spring	Autumn	Spring	Autumn
0	24·3	18·8	97·5	78·3
2	48·4	21·8	286·2	79·5
4	50·8	29·2	344·2	140·8
6	66·6	27·4	470·0	95·6
8	73·9	26·4	531·4	93·0
LSD (P =0·05)	13·3		37·0	
,, (P =0·01)	17·7		49·1	

TABLE 3. Percentage distribution of heads and of total head-length in response to increasing level of ammonium nitrate applied in spring

Ammonium nitrate (cwt./acre)	Head-length groups (cm.) <4·0	4·1–6·5	6·6–8·9	>9·0
		Heads		
0	55·5	39·3	5·2	0·0
2	22·0	35·8	34·5	7·7
4	21·2	24·1	31·7	23·0
6	17·6	27·4	26·3	28·7
8	16·7	28·5	21·9	32·9
LSD (P =0·05)	11·4	9·2	5·0	4·6
„ (P =0·01)	15·1	13·0	6·7	6·0
		Total head-length		
0	40·5	50·2	9·3	0·0
2	12·0	33·2	43·0	11·8
4	10·5	19·0	36·5	34·0
6	8·2	20·9	29·0	41·9
8	7·7	21·0	23·7	47·6
LSD (P =0·05)	8·6	4·6	6·5	5·7
„ (P =0·01)	11·4	6·0	8·6	7·6

applied in the spring was responsible for bringing about a shift towards greater head-length. The correlation between the size of the nitrogen application and the percentage of total heads and of total head-length falling into the >9 cm. grouping is very close indeed, $r=0{\cdot}99$, $P=0{\cdot}01$ in each instance.

The increased head-length in response to nitrogen appears to be due to the greater elongation of all the heads produced by the plant, with the possible exception of those arising from the latest-formed tillers.

Autumn treatments had no significant effect on either of these quantitative responses, but there was a significant spring/autumn treatment interaction ($P=<0{\cdot}01$) in terms of the percentage distribution of heads and total head-length in the <4 cm. grouping. In each case after applying ammonium nitrate in spring the reduction in the proportion falling into this category was less marked in those plants which had received the greatest amounts in the autumn.

Direct estimation of potential seed-yield from the data given in the Tables 1–3 would presuppose uniform seed-bearing capacity for heads of all lengths. It has already been shown that the number of seeds set per cm. falls with decreasing head-length (6), which suggests either a lower percentage seed set due to inadequate pollination, or a lower intrinsic seed-bearing capacity. In order to resolve this question for the clone of S48 under study, median sections 1 cm. in length were taken from a number of heads of varying sizes and the general relationship obtained is given in Fig. 1.

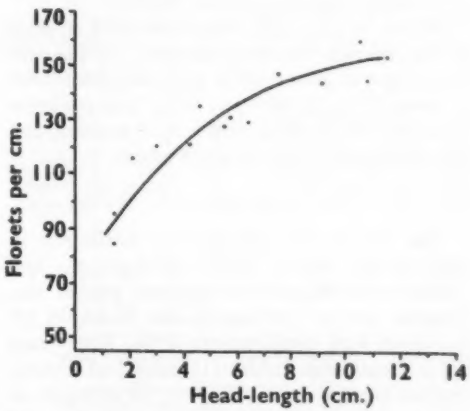

Fig. 1. Number of florets per cm. related to head-length.

The number of florets per linear cm. varies according to the length of head, there being a range from 85 to 146 florets in the clone studied. For optimum seed yield, therefore, it

TABLE 4. Effects on total heads and head-length per plant of dressings of nitrogen applied in autumn, spring, and autumn + spring

Treatment: ammonium nitrate (cwt./acre)	Mean heads per plant	Total head-length per plant
Control (no manuring)	27·2	118·2
4 cwt./acre in autumn	26·5	120·7
2 cwt./acre in autumn + 2 cwt./acre in spring	48·6	260·4
4 cwt./acre in spring	58·8	373·3
LSD (P =0·05)	10·1	33·9
„ (P =0·01)	18·2	45·4

appears necessary to have the greatest possible number of long heads, with the absolute minimum of short heads. Furthermore, these data suggest that nitrogen increases the head-length, at least in part, by increasing the rate of floret differentiation, and that when nitrogen level is low a reduced supply of amino-acids and other assimilates limits this process. This is compatible with previous observations which show that increased nitrogen level has no apparent effect on vegetative timothy apices but that after floral induction the juvenile inflorescences are always longer at higher nitrogen levels (4).

The single- and split-dressings in Experiment 2 revealed a similar pattern (Table 4).

There was no effect from nitrogen applied in the autumn; the response given by the split dressing was of the order to be expected from a spring dressing of 2 cwt./acre. It is probable that the whole effect of the split dressing can be attributed to the spring fraction.

DISCUSSION

The value of nitrogenous fertilizers in stimulating fertile tiller production, and therefore seed yield, in pedigree grasses was pointed out by Stapledon and Beddows (5) working with cocksfoot in 1926. Five years later Evans and Calder (1) published a comprehensive survey of the effects of nitrogen on the seed production of a number of Aberystwyth grass varieties, including S51 timothy, which gave a much larger seed yield after a spring dressing of 2 cwt./acre nitro-chalk. Since then the use of nitrogenous fertilizers to stimulate seed yield has become common practice, but even today the correct quantity to apply and the opportune time to apply such manurial dressings remain a subject for debate.

The present trend towards the importation of more foreign herbage seeds at competitive prices makes it imperative for growers of indigenous varieties for seed to look for methods of exploiting to the maximum their seed potential, whilst at the same time keeping costs to a minimum. Careful evaluation of the use of nitrogen to increase seed yield could well make a useful contribution towards these ends.

A first requirement in any such study is a knowledge of the seasonal pattern of tillering of the variety in question and the relationship which this pattern bears to head production. Langer (3), using pot plants, has contributed much information from his admirable study of these problems in S48 timothy, which provides a sound basis for future research into problems concerned with manuring and management of timothy seed crops. He showed that the size of head varied linearly with the date of origin of the tiller bearing it and therefore that later-formed tillers would bear smaller heads. It was noted also that only tillers arising before the end of July could produce inflorescences, after which point growth-stage and daylength presumably prevented floral induction. Timothy does not normally require low-temperature exposure or short-day induction for the production of inflorescences (2), and so for maximum head production it is necessary to produce the greatest number of competent tillers before the end of July.

The data in Table 2 indicate that ammonium nitrate applied as a spring dressing in mid-March at 2 cwt./acre had the greatest effect on head production and was sufficient to double

the number of heads produced and treble the total head-length per plant. The response to dressings of ammonium nitrate continued up to 8 cwt./acre; this was the highest applied and in terms of elemental nitrogen corresponded to a dressing of nitro-chalk at 18 cwt./acre, which is considerably in excess of even the highest rates applied in current agricultural practice.

In contrast, no significant response to dressings of ammonium nitrate in the autumn was detected at any of the rates applied. It is possible that the small size of the plants at the time of the autumn treatment precluded any measurable response, but even at this stage, in terms of tiller number they were equal to plants taken from field crops in August of the sowing year. Within the reservation of this limitation the results given are still applicable to first harvest year material of S48 timothy, although in this instance it might be possible to obtain a response by applying fertilizer at a much earlier date. Lateness of harvesting prevents this with more mature crops.

The data dealing with total number of heads and percentage of head-length distribution (Tables 1–3) confirm the introductory suggestion that some measure of control might be exercised over the proportion of small heads in a crop by manipulation of the nitrogenous manuring. A very large decrease is brought about by the first application of ammonium nitrate at 2 cwt./acre, but succeeding dressings at higher levels have little further effect.

The greatest value of applying nitrogen in spring is the increase in the percentage of heads and total head-length in the >9 cm. category; an almost absolute correlation exists between each of these quantitative responses and the amount of fertilizer applied. Longer heads have a greater seed-bearing capacity per unit length and produce larger seed (6); therefore, to exploit the seed-bearing capacity of a plant to the full it is necessary to produce as great a percentage of heads as possible in the longer head-length groups.

In the absence of relevant data it would be out of place to discuss here the comparability of single plants and drill crops. Competition will obviously exert some influence upon heading and the distribution of heads, but it is probably fair to assume that in the first harvest year, when this factor is at a minimum, the processes of tillering and inflorescence production will be similar to those observed in single plants. The current practice of reducing the seeding rate of timothy crops to 2 or 3 lb./acre makes this even more probable.

Within the range of treatments studied there are good grounds, at least for timothy seed crops prior to the first harvest, for applying a minimum amount of nitrogen in the autumn and for giving as much as possible in the spring. Studies at the Welsh Plant Breeding Station (unpublished) have shown that the clonal material of S48 used in these two experiments will respond to dressings of ammonium nitrate up to a maximum of 18 cwt./acre (40·7 cwt./acre nitro-chalk, 15·5% N), but that 85% of the total increase obtainable will result from an application of 8 cwt./acre (18 cwt./acre nitro-chalk).

In conclusion, it is fair to say that, while this provides a good indication of the size of the optimum spring dressing, the actual amount to be applied in a particular circumstance now appears to be a matter on which the agricultural economist may be able to give useful advice.

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THE PRODUCTION OF EARLY SPRING GRASS

II. The effect of autumn management and nitrogenous manuring on the production of early spring grass from different sites throughout England and Wales

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The effects of autumn management and nitrogenous manuring on the production of early spring grass were studied from 1954 to 1957 on farms throughout England and Wales.

The most important management factor influencing spring yields was the application of spring nitrogen. In the early spring 6 to 10 lb. of dry matter were produced per lb. of nitrogen applied. Autumn nitrogen increased herbage yields in the autumn by 8 to 17 lb. of dry matter per lb. of nitrogen applied.

Italian and perennial ryegrass responded well to autumn nitrogen but it was important to graze off the extra growth fairly quickly to prevent the sward becoming too open. The yield of ryegrass swards which received spring nitrogen were very much higher if they were grazed during the previous September and October than if they had been rested during those months.

In two years neither the autumn management nor autumn fertilizer appeared to influence the spring yields of cocksfoot, timothy or meadow fescue swards. In one year, however, when autumn growth was poor, autumn nitrogen and resting resulted in slightly better yields on these swards in the following spring.

It is suggested that resting swards during September and October to build up "reserves" is relatively unimportant in relation to the yields of grass in the following spring.

INTRODUCTION

Part I of this paper (Baker, (2)) reported the results of experiments designed to study the effect of autumn management and different levels of nitrogenous manuring on the production of early spring grass from a general purpose ley. These experiments were located at The Grassland Research Institute, Hurley, and were started in 1954. In co-operation with the National Agricultural Advisory Service, centres were established at the same time to study the effects of similar manurial and management treatments under practical conditions with a wide range of soil types and climatic factors. These sites were on commercial farms whose geographical distribution is shown in Fig. 1. The leys were not specifically sown for this experiment, but a sward that the farmer would normally have used for early spring grass production was selected at each centre. The sward types used were thus not uniform and included short-term leys of Italian ryegrass, long-duration leys of various grass/clover mixtures and one or two permanent pastures.

EXPERIMENTAL DESIGN AND PROCEDURE

The fertilizer and grazing treatments were carried out by the farmers. For ease of management only one block was laid down at each centre, and usually a whole field was used for the experiment. Similarly a simple split-plot technique was used. The treatments were applied in strips so that the fertilizer and management treatments were at right angles to each other.

Fig. 1. The distribution of centres 1954–1957

Grazing treatments

Three grazing treatments were applied during the autumn of 1954 and 1955, corresponding to treatments A, B and C of the Hurley experiment (Baker (2)):

A. Rest September and October
B. Graze September, rest October
C. Rest September, graze October

In 1956/7 a fourth treatment, corresponding to treatment D at Hurley, was added, viz:

D. Graze September and October

The swards were cut or grazed down by the end of August, and were subsequently grazed by cattle only. During the autumns of 1954 and 1955 the appropriate plots were grazed once or twice in the month. In 1956 grazing was continuous during any monthly period on plots due for grazing. In all cases the bulk of autumn growth was grazed off in November and the swards were then rested until the spring.

Nitrogen treatments

There were 4 nitrogen treatments:

Nitrogen lb. per acre		
Autumn		Spring
0		0
	×	
52		52

The autumn dressings were applied during the first week of September, and the spring dressings at the end of February or beginning of March.

Sampling techniques

Herbage yields were estimated by techniques similar to those used at Hurley (Baker (2)) and 5 sample areas, each of 6 square yards, were cut for weighing on each plot (3).

RESULTS

Where applicable, centres have been grouped into sward types depending upon the dominant grass species. These types are:

(1) Italian ryegrass
(2) Perennial ryegrass
(3) Cocksfoot/timothy/meadow fescue.

The latter were cocksfoot, timothy/meadow fescue or cocksfoot/timothy/meadow fescue swards. Centres where ryegrass was mixed with other grasses in fairly even proportions have been excluded from the sward type comparisons.

Average spring yields

The average spring yields for each year at all centres are given in Table 1. All the plots were to have been sampled when the most advanced plot had approximately 1000 lb. of dry matter per acre. However, in certain cases (mostly in 1956) the spring growth was so slow that the plots had to be sampled before that. In the springs of 1955 and 1956 nearly all swards were sampled during the second half of April and the first few days of May (the exceptions were 4 Italian and 2 perennial ryegrass swards which

TABLE 1. The effect of autumn management and nitrogenous manuring on the yield of spring grass (lb. dry matter per acre)

Year	Autumn rest period	Nitrogen treatment (each application 52 lb. nitrogen per acre) Nil	Autumn	Spring	Autumn plus spring	Standard error for each mean
1954/5	Sept.	610	790	1050	1040	±61
10 centres	Oct.	690	800	1000	1020	±61
	Sept. + Oct.	700	770	1090	1030	±61
1955/6	Sept.	330	330	680	720	±41
19 centres	Oct.	360	330	690	700	±41
	Sept. + Oct.	330	330	640	630	±41
1956/7	Sept.	580	530	1050	1050	±52
11 centres	Oct.	600	660	1170	1240	±52
	Sept. + Oct.	520	570	1080	930	±52
	Nil	570	680	1140	1150	±52

were sampled during the first half of April). In 1957 all the swards but one were sampled between 27 March and 12 April. (An Italian ryegrass sward on the edge of Exmoor was not sampled until 24 April.) There was a considerable seasonal effect on spring yields: 1957 had the earliest spring, and yields similar to those of 1955 were produced 2 or 3 weeks earlier. In 1956 yields were smaller and relatively late.

Italian ryegrass tended to be earlier than the other species, and centres in south-west England were generally ready for sampling 2 or 3 weeks earlier than those elsewhere. These general trends were, however, considerably modified by, for example, age and vigour of the swards, general level of soil fertility, and physical characteristics such as altitude and aspect. There was little correlation between earliness and geographical position. The south-west was, however, generally earlier than the rest of the country.

Neither the autumn-grazing management nor autumn fertilizer treatment had any appreciable effect on the average spring yields. Spring nitrogen increased the average herbage yields by 310 to 530 lb. per acre, depending upon the season.

Effects of autumn nitrogen on autumn growth

No estimates were made of herbage growth in the autumn of 1954; in 1955 and 1956 the yields of plots rested throughout both September and October were measured at the end of October. The results of applying 52 lb. of nitrogen per acre in the first week of September on growth up to the end of October are shown in Table 2.

The autumn of 1955 was generally very dry, and, without fertilizer, only 4 cwt. of dry matter was produced per acre during September and October. The application of nitrogen stimulated considerable extra growth in the case of Italian ryegrass. The response from perennial ryegrass was smaller, and smaller still from swards of cocksfoot, timothy and meadow fescue.

In 1956 there was very little difference in yield between the various sward types, and the application of nitrogen increased the average yields by 600 to 650 lb. per acre.

The influence of autumn management on the spring growth of different sward types

Three grazing managements (A, B and C) were applied at all centres. The overall effects of these managements and the 4 fertilizer treatments on different sward types during the 3 years are given in Table 3.

Strict comparison between the yields of the different species should not be made because the sampling dates were variable, but the orders of yields within the different types are comparable. Autumn nitrogen had little consistent effect on the average spring yields. In the case of ryegrass swards, however, there

TABLE 2. The effect of autumn nitrogen (applied early September) on herbage yields at end October

Treatment—Rest September and October
Yield lb. dry matter per acre

Year	Sward type	No Nitrogen	Nitrogen 52 lb. per acre	Standard error for each mean
1955	Italian ryegrass (7 centres)	440	1320	±160
	Perennial ryegrass (6 centres)	440	1050	±63
	Cocksfoot/timothy/meadow fescue (3 centres)	470	880	±53
1956	Italian ryegrass (3 centres)	960	1560	±32
	Perennial ryegrass (3 centres)	800	1450	±49
	Cocksfoot/timothy/meadow fescue (5 centres)	910	1520	±56

TABLE 3. The effect of autumn management and nitrogen fertilizers on the spring yield of different sward types

Herbage yields lb. dry matter per acre
Nitrogen treatment
(each application 52 lb. nitrogen per acre)

Sward type	Autumn rest period	Nil	Autumn	Spring	Autumn plus spring	Standard error for each mean within a sward type
Italian ryegrass (11 centres)	Sept.	440	390	770	810	±55
	Oct.	420	390	730	800	
	Sept. + Oct.	340	380	690	640	
Perennial ryegrass (10 centres)	Sept.	400	430	840	850	±61
	Oct.	480	480	990	950	
	Sept. + Oct.	370	400	880	670	
Cocksfoot/timothy/meadow fescue (8 centres)	Sept.	480	460	950	910	±72
	Oct.	500	520	980	1020	
	Sept. + Oct.	490	570	940	1000	

was an interaction between autumn nitrogen and autumn grazing. When autumn nitrogen was applied to Italian and to perennial ryegrass swards not grazed during September and October, herbage yields in the spring were lower than when the swards were grazed in either month. This was particularly marked in the case of ryegrass swards that received nitrogen in both autumn and spring, and the pattern was similar at nearly all these centres. On cocksfoot/timothy/meadow fescue swards there were no such consistent trends and spring yields were not so much affected by autumn management.

In 1956/7 the effect of grazing throughout September and October was similar to that of grazing in either month. The comparison of grazing or resting from early September to the end of October is given in Table 4. Results from a single centre in 1955/6, where there were 3 separate ryegrass swards (H1, S22 and Commercial Italian) to which these two grazing managements only were applied, are also given in this Table.

The complete resting of ryegrass swards during September and October after applying nitrogen resulted in lower spring yields than those of swards that were continuously grazed. Results from other swards again showed little response to autumn management.

TABLE 4. The effect of either grazing or resting for whole of September and October on the spring yields of different sward types

		Herbage yields lb. dry matter per acre Nitrogen treatment (each application 52 lb. nitrogen per acre)				
Sward type and year	Treatment during September and October	Nil	Autumn	Spring	Autumn plus spring	Standard error for each mean
Short-lived ryegrasses (3 swards 1955/6)	Grazed	240	360	750	690	±55
	Rested	180	90	330	330	±55
Short-lived ryegrasses (3 centres 1956/7)	Grazed	430	590	970	1050	±53
	Rested	430	410	930	690	±53
Perennial ryegrasses (3 centres 1956/7)	Grazed	780	950	1360	1260	±98
	Rested	550	640	1140	840	±98
Cocksfoot/timothy/meadow fescue (5 centres 1956/7)	Grazed	540	570	1120	1150	±47
	Rested	570	620	1140	1120	±47

TABLE 5. The average increase in total herbage yield for each lb. of nitrogen applied

	Yield lb. dry matter	
Period	Average of sites in England and Wales Increase in herbage yield	Hurley experiment (Cocksfoot, timothy and meadow fescue) Increase in herbage yield*
Spring 1955	6·0	8·1
Spring 1956	6·6	7·5
Spring 1957	10·4	10·2
Autumn 1955		
Italian ryegrass (7 centres)	16·9	—
Perennial ryegrass (6 centres)	11·5	—
Cocksfoot/timothy/meadow fescue (3 centres)	7·9	11·8
Autumn 1956		
Italian ryegrass (3 centres)	11·5	—
Perennial ryegrass (3 centres)	12·4	—
Cocksfoot/timothy/meadow fescue (5 centres)	11·7	22·7

*These yields are taken from the sampling dates closest to the average sampling date on the outside trials

TABLE 6. The effect of autumn management and nitrogenous manuring on the spring growth of cocksfoot/timothy/meadow fescue swards. (Mean of 3 centres 1955/6)

	Herbage yields lb. dry matter per acre Nitrogen application 52 lb. per acre				
Autumn rest period	Nil	Autumn	Spring	Autumn plus spring	Standard error of a mean
September	270	370	590	580	±76
October	360	360	590	640	±76
September plus October	370	500	620	790	±76

DISCUSSION

In this series of trials, as in the Hurley experiment, the weather caused considerable differences in the results from year to year. The major management factor influencing spring yields was the application of spring nitrogen, but the amount and the time of the response varied with the season. In Table 5 the average increases from nitrogen applications are compared with those obtained at Hurley. The average responses to nitrogen were low in 1955 and 1956 (6·0 to 6·6 lb. of herbage per lb. of added nitrogen). In 1957 an average of 10 lb. per lb. was obtained at a considerably earlier date. Any additional benefits from spring nitrogen during May and June were not measured, but it should be noted that at Hurley the eventual response per lb. of spring nitrogen reached 12, 9 and 28 lb. of herbage in the 3 successive seasons.

The increased yields obtained during September and October from nitrogen were greater than those obtained during the early spring. In 1955, when autumn growth was generally restricted by drought, the best response to autumn nitrogen was obtained on Italian ryegrass and the worst from non-ryegrass swards. In 1956 autumn growth was good and all swards averaged about 12 lb. of extra herbage per lb. of nitrogen. This response, however, was only just over half that obtained from the cocksfoot/timothy/meadow fescue sward at Hurley. There was no evidence that autumn applications of nitrogen had any direct effect on spring growth.

In 1954/5 and 1956/7 the results of autumn grazing on the spring yields of the cocksfoot/timothy/meadow fescue swards were not consistent; and their effects were unimportant when compared with that of the application of spring nitrogen. However, in the poor growing autumn of 1955/6 there was some evidence that, on the 3 non-ryegrass swards, growth in the following spring benefited from resting in September and October—particularly when autumn nitrogen had been applied (Table 6).

The growth of Italian and perennial ryegrass swards in the spring was influenced by treatment in the preceding autumn. There were 21 centres where the sward was predominantly ryegrass, and at 18 of these higher yields were obtained from swards which were grazed during September and/or October than from swards which were rested during both months. If ryegrass swards are allowed to grow unchecked in the autumn the formation of a complete herbage canopy reduces the amount of light reaching the growing points and young leaves. This can decrease tillering (Mitchell (5)). There is also a tendency for the lower internodes of the tillers to elongate and to raise the growing points and young roots well above soil level. Many of these tillers die or are damaged during subsequent defoliation, and eventually both the plant and tiller population are greatly reduced (Baker (1)). Similar changes were observed during this experiment on ryegrass that received nitrogen in the autumn. When these swards were rested during September and October it was quite obvious that they were much more open than swards grazed during that period. In the following spring, although the surviving tillers and plants on the rested swards may have been more vigorous, there were not enough tillers and plants to equal the yields from the denser swards created by more frequent grazing. The tiller and plant densities of cocksfoot/timothy/meadow fescue swards were not so susceptible to autumn treatment, and any slight changes in density were compensated by increased production per tiller.

May and Davidson (4) have queried the hypothesis which supposes that plant food "reserves" are accumulated in the roots of pasture plants, and subsequently transferred, during times of stress, to the above-ground herbage shoots. In the present series of experiments there was no evidence that resting a grass sward during September and October to build up "reserves" was a critical factor in the production of early spring growth. In the Hurley experiment (Baker (2)) there was no correlation between the soluble carbohydrate content in the stem bases, or roots, during November and subsequent spring yields. In the trials throughout England and Wales other factors such as plant density in ryegrass

swards, the application of nitrogen in the spring, and climatic conditions, appeared to have far more effect on spring production than the build-up of plant reserves during the autumn. It should not be inferred from this that *continuous* defoliation *during the winter* (when growth and photosynthesis are low) will have no deleterious effect on growth in the following spring.

Although these experiments were designed to test the effect of autumn managements and nitrogenous fertilizing on spring growth, they have shown that worthwhile and quite reliable responses in herbage yields can be obtained from nitrogen applied in early September. This is particularly true of Italian and perennial ryegrass. Provided the extra ryegrass herbage is utilized soon after it has grown there will be no detrimental effect on growth in the following spring. Cocksfoot, meadow fescue and timothy also respond to autumn nitrogen and their herbage need not be utilized until November.

Spring nitrogen was again shown to be the most important single management that influenced spring growth, but the earliness and quantity of spring grass is very dependent upon the weather. Although autumn grass may not have as much feeding value as spring grass, the consistent results obtained throughout the country from autumn nitrogen application suggest that the adoption of this technique should be seriously considered as a method of extending the grazing season.

ACKNOWLEDGEMENTS

Our sincere thanks are due first to the farmers who so generously provided facilities for these experiments and second to the many officers of the N.A.A.S. who assisted in the establishment and management of these trials. Acknowledgements are due to Dr. William Davies for his continued interest and to Dr. T. Jones for starting this work during 1954/5.

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ADVANCE NOTES ON RESEARCH

AFTER-EFFECTS OF IRRIGATION

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In the first trial of a series designed to examine selection indices in grass breeding, *Lolium perenne*, variety S24, was grown in five related population densities in randomized blocks on a sandy loam at the Plant Breeding Institute, Cambridge (1). The herbage was cut frequently to a height of one inch. To half the plots sufficient water was added to ensure the calculated soil moisture deficit did not exceed two inches: the remainder were not irrigated. In the dry summer of 1959, the second harvest year, a marked increase in yield was obtained as a result of the application of 8·2 in. of water during the period 12 May to 25 September. This communication reports on the after-effects of this 1959 irrigation shown at the first 1960 harvest (17 March).

The increase in dry herbage from the previously-irrigated compared with the non-irrigated plots varied from 76% to 180% in the different population densities. During the autumn and winter of 1959/60, more plants died in the non-irrigated than in the previously-watered plots, especially at the highest densities (Table 1).

Mean weight per plant was increased by 1959 irrigation, and was also affected by population density: the log mean weight was negatively correlated, in an entirely linear manner, with log density. Whereas previous irrigation increased the yield per plant by a similar proportion in all spaced densities, no such increase was detected in the mean weight of individual sward plants.

The tiller production per plant was also increased by the previous year's irrigation and the lower the population density, the more tillers per plant. However, in the 24 in. plots, there were fewer tillers per plant than would be indicated by a linear relationship between log

TABLE 1.

Population		Yield per acre (cwt.) Fresh	Yield per acre (cwt.) Dry	% wt. increase with irrigation Fresh	% wt. increase with irrigation Dry	% dry matter	% reduction in plant numbers (autumn and winter 1959/60)
Sward	N	15·0	4·3			28·6	40·2
	I	28·0	7·6	86·6	75·8	27·0	4·9
3×3 in.	N	12·8	3·9			31·9	21·6
	I	33·2	8·8	159·0	123·7	26·5	6·9
6×6 in.	N	11·6	3·4			30·0	4·9
	I	36·3	9·5	214·3	178·8	26·2	0·4
12×12 in.	N	12·6	2·8			22·7	1·4
	I	23·4	5·3	86·1	87·3	22·7	0·7
24×24 in.	N	11·0	2·5			22·5	—
	I	18·6	4·4	68·9	79·5	24·0	—

N=Non-irrigated plots I=Irrigated plots

TABLE 2.

Population		Plants per sq. ft.	Mean dry weight per per plant (g)	Mean tillers per plant	Mean dry tiller weight (g × 10,000)
Sward	N	22·3	0·23	13	173
	I	39·0	0·22	12	184
3×3 in.	N	11·9	0·38	19	200
	I	14·3	0·72	33	221
6×6 in.	N	3·75	1·05	54	195
	I	3·93	2·81	129	220
12×12 in.	N	0·99	3·35	151	223
	I	0·99	6·25	327	191
24×24 in.	N	0·25	11·56	458	251
	I	0·25	20·75	645	321
			Variance ratios (log transformed data)		
Population	Sward v rest		1,353***	1,775***	29·96***
	Rest linear		1,642***	2,198***	24·30***
	Rest quadratic		—	10·82**	16·74***
N v I			108·6***	130·1***	4·31*
Population × (N v I)			8·48**	14·43***	3·43*
Coefficient of variation			6·14%	3·15%	15·26%

TABLE 3.

Population		Mean percentage (on total organic matter) Nitrogen	Ash	Fibre
Sward	N	4·27	8·52	33·9
	I	3·53	8·18	33·5
3×3 in.	N	4·25	8·77	33·6
	I	3·55	8·93	34·1
6×6 in.	N	4·23	8·07	34·8
	I	3·84	8·52	34·2
12×12 in.	N	3·95	8·64	32·1
	I	3·61	7·98	31·7
24×24 in.	N	3·91	8·79	32·9
	I	3·90	8·49	33·9
L.S.D. (P=0·05)		0·257	0·626	1·44

N = Non-irrigated I = Irrigated

density and log tiller number. In addition, the mean dry weight per tiller was increased by irrigation and although tillers removed from the 3 in., 6 in. and 12 in. plots were all of similar size, larger than from the sward, those from the 24 in. plots were considerably the heaviest (Table 2).

Herbage samples were analysed for nitrogen, fibre and ash. The only main treatment effect on nitrogen was that of irrigation, previous watering reducing the nitrogen content of the herbage. The higher the population density the greater this effect: at the widest spacing no differences were detectable. There were no significant effects of prior irrigation on fibre or ash content (Table 3).

DISCUSSION

This report shows that differences in herbage yields, resulting directly or indirectly from the previous year's irrigation, may be detected in early spring. However, more investigations are needed to distinguish between the direct and the indirect effects such as might result from cutting irrigated and non-irrigated plots on the same dates during 1959. The prolonged effect of irrigation, which has been shown to vary in amount from one density to another, can be better understood by splitting yields into components.

In most densities, higher mortalities on non-irrigated plots contributed to their lower

yields; indeed in the swards the whole of the reduction in the yield from the previously non-irrigated plots seemed a consequence of the fewer plants present. In other densities there was a lower mean yield per plant, made up of fewer and even smaller tillers from the non-irrigated compared with the previously-irrigated plots. After the early spring cut the natural plasticity of the grass plant would compensate for the fewer plants present in the non-irrigated plots by an increase in their individual weight.

No completely satisfactory explanation can be put forward to account for the nitrogen figures; further studies are necessary to explain the differences.

The varying responses of the population densities to irrigation point to the danger of extrapolation of data in both grass-breeding techniques and agronomic practice. That after-effects of irrigation on yield occurred, there can be no question, nor can their practical significance in the production of early bite be doubted.

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GRASSLAND AND SOIL STRUCTURE*

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Soil structure has been defined in many ways, but Jongerius in 1957 probably formulated the most apt description when he wrote that 'Soil structure is the spatial arrangement of the elementary constituents, and any aggregates thereof, with the cavities occurring within the soil.' From this statement it is quite clear that to describe soil structure in the form of the aggregates alone is analogous to describing the human body purely in the form of its skeleton. This does not mean that the peds have lost any of their importance, or significance, but rather that other factors implied in the definition, such as interpedal space, porosity of the ped, soil/water/air relationship, stability etc., are of equal importance.

Of all soils the ones with the best and, agriculturally, the most useful structure are the chernozems of Russia and prairie soils of North America. The chernozems or black earths were first recorded in Russia by Dokuchiev in the latter half of the nineteenth century, originally due to their black colouring and uniform areal distribution. Investigation has shown that these soils are usually neutral, or thereabouts, with calcium as the predominent base. Free $CaCO_3$ occurs at depth, usually 3 feet or more, in the form of pseudomycelia or concretions. Structurally it is the agriculturalist's ideal, the crumb structure being so well developed and stable that a common statement is that if a spadeful is tossed into the air it falls apart like a handful of small grapes. This state is not confined to the top six inches or so but it may have a vertical extent of three feet or more, although the colour may pale at depth, due to the decreasing quantity of organic matter and the beginning of the free $CaCO_3$ deposition.

The main reasons for these physical characteristics are generally assumed to be due to the climatic regime which is the dominant soil-forming factor. Firstly, it is usually thought that the soils occur in areas where there is insufficient precipitation to support a forest cover, and it is therefore natural grassland. Secondly, in this sub-humid zone, the rainfall just strikes the critical balance with the vegetational demand for water, so that there is little or no surplus moisture in the profile. Consequently, little leaching of the soil occurs and nothing is lost into the ground water or rivers. For these reasons one can see that there will be a continuous build-up of organic matter within the profile, for under such favourable conditions the dead organic matter in the form of litter and roots is readily incorporated in mull-humus form into the soil to great depths. As the organic-matter content increases so, to a lesser degree, do the mineral nutrients, for, although weathering takes place, very little is lost from the organic cycle. The humus content of these soils varies from 120 to 240 tons per acre in North America and from 400 to 600 tons per acre in Russia. It is possible that in these grassland soils, therefore, the organic matter content is very many times greater by weight and volume than that contained in the best possible crop grown on these soils. Further, it seems that mineralization of the organic matter in the soil is very slow, thus providing a vast reservoir of plant nutrients.

The C/N ratio is usually of the order of 10: 1, with an average carbon content of approximately 55%. It is, therefore, reasonable to assume that chernozems contain in every acre 60–300 tons of organic carbon, 6 to 30 tons of nitrogen, with a reserve of 6 to 30 tons of various mineral plant nutrients not subjected to leaching.

Chernozems or prairie soils do not occur naturally in the British Isles, although the thin

*Paper read at the joint meeting of the British Grassland Society and the British Society of Soil Science in London on 8 December 1960.

well-structured soils found on the chalk approximate quite closely in many ways. The structure is good and very stable and the pH and mineral nutrient status is high. Avery (1958) demonstrates this quite clearly in his paper 'A sequence of beechwood soils on the Chiltern Hills'. The most significant factor in the changeover from the stable well-structured rendzinas and brown calcimorphic soils is the increase in leaching and loss of $CaCO_3$ and its stabilizing effect. This factor is widespread in the forested and formerly forested soils which largely cover the British Isles, and with moderate acidification of the profile one finds clay eluviation and there is quite often a loss of the stable granular top-soil structure. The increased clay content in the lower horizons often leads to a restricted root development due to the unfavourable structure, and hence a much poorer yield of mineral nutrients to the surface from the weathering material below. This process would appear to be self-accelerating, particularly when arable cultivations are practised. Bearing this in mind, and as Dr. William Davies in his presidential address in 1948 reminded us, 'Grassland is a place in the vegetational succession standing somewhere between bare ground and the forest climax', grassland is therefore, over the major portion of Great Britain, an artificial vegetational state.

The foregoing does not mean that the soils of Great Britain are unsuitable for grass growth and production; rather the opposite in fact, for many reasons. With improved management techniques, particularly the addition of lime and phosphate, the advent of new seeds, better mixtures, and other factors, our soils may prove to be the best grass producers, different from the chernozems which are the best soils produced under grass.

Many workers have proved that well-managed grassland is the best way, in the present state of knowledge, of obtaining a good stable structure, but the main limitation is that so far, over a short period, this improvement is confined to the top few inches. Low convincingly demonstrates the increasing aggregation and stability under a grass-sward and further shows that the longer a field is under grass so does the aggregation and water-stability increase. In fact, as his 'pasture standard' he cites grassland at least 110 years old and says 'the soil on this old pasture, as a result of field drainage, probably represents the nearest approach to a chernozem in Britain'.

Although we know that grassland does improve structure, it is worthwhile considering what constitutes good structure and how far this does occur. Generally, taking the ideal, one should find in a well-structured soil 70–80% of the total mass in stable aggregates plus all the other properties which go with this and were spoken of earlier. However, most good soils, on average, rarely have more than 40–50% aggregation, and sandy soils, soils low in organic matter and badly puddled heavy clay soils commonly show that only approximately 20% of their mass is aggregated in varying degrees of stability. Unless a soil is very sandy this low figure shows a physical condition hardly conducive to healthy plant growth.

The problem is, then, one of increasing soil aggregation into a stable crumb or granular form and there are two main ways of aggregation. Firstly the breakdown of larger units, and secondly the build-up of smaller particles. There are then five major factors operative in one or both of the former processes. These are: (1) alternate wetting and drying, (2) alternate freezing and thawing, (3) the actual physical activity of roots and soil fauna, (4) the influence of decaying organic matter and other forms of life, and (5) the modifying effect of adsorbed bases on the dry particles. All the above factors play some part in forming a good soil structure and it is obvious that grassland, well-managed, can help and utilize all of them.

One of the major differences between a grass and a forest cover is the type of organic matter which passes into the solum. Natural forest seasonally deposits its litter on the surface of the soil, resulting in a litter-covered surface which tends to persist for two reasons. Firstly, it is too large in quantity for the soil fauna and bacteria to incorporate into the mineral soil rapidly, and secondly, owing to the persistence of the litter cover, there is a consequent development of acid leachates which

impoverish the top-soil of bases and later in the sequence may possibly help to move clay down the profile.

Grassland has a reasonably well distributed litter fall which is readily incorporated in the surface soil in the form of mull-humus and, provided the pH of the land is kept fairly high, such leaching of bases as does take place may easily be replaced by the addition of fertilizers. Considering that most of our soils have been developed under some form of natural forest, leaching of bases and the tendency to clay-shift down the profile will have taken place. Therefore, the first factor in management is the replacement of the bases by lime and fertilizers. Of these, lime is probably the most important, for it enriches the soil and the consequent litter enabling the soil fauna to flourish, therefore facilitating the formation of mull humus and its ready incorporation into the mineral soil. This is a major factor, for it not only helps to form a good structure but also stabilizes it. Indeed, today some soil chemists are seriously thinking that a slightly acid soil may not be the ideal they once thought and they are now thinking of soils with a neutral, or even slightly alkaline, reaction. With present fertilizers and management techniques any nutrient deficiency which may be due to the slightly alkaline conditions can be easily remedied. This is a more logical approach, for the high lime content serves a threefold purpose: it helps the formation of mull-humus and its easy incorporation; secondly, it encourages soil fauna; and thirdly it may prevent any tendency towards clay eluviation.

However, grassland as a crop has its serious defects, particularly when it is used for a dual purpose, that is, firstly the production of grass for stock-feed, and secondly as a soil conditioner. Very often it is cropped indiscriminately, with great use of fertilizers to produce the maximum yield in the shortest possible time, with the least attention being paid to the medium in which it grows. High-yielding leys very often have their roots concentrated in the top few inches, as Baker and others have shown, so that the ameliorating effects of grassland upon soil structure are confined in most leys to the top 6, or even 3, inches. The position is further aggravated when concentrated grazing takes place, for not only does surface poaching and close packing of the soil usually occur, but from observation alone one finds an increase in tillering, which appears to be accompanied by shallow-rooting, a process the author does not pretend to understand. Concomitant with these factors, the rooting system seems to spread laterally in the form of a dense root mat and vertical penetration is at a minimum. When considering the chernozem, a salient factor was the deep-rooting nature of the grasses, presumably in search of water and its contained nutrients in the sub-humid climatic conditions of this soil zone. Allied to this is Low's statement about the old Northamptonshire pasture and the under-drainage which would create a drier profile, and hence a deeper rooting zone.

Tillage of leys is not a helpful factor in the production of a good stable structure. The mould-board plough usually buries the well-aggregated soil under less stable material, which has to be worked by machinery to produce an artificial seed-bed which, to say the least, is often unstable and frequently disperses under rainfall giving rise to surface capping and general dispersion of the machine-made structure into its component elements; a picture all too common in these days of power-farming. Secondly, the plough often creates a pseudo A-horizon sharply demarcated from the remainder of the profile below; another factor which in many cases inhibits downward penetration by roots. This panning of the soil may to some extent be aggravated by the hydraulic plough in common use today, for this increases compression of the soil by the rear-wheels of the tractor, particularly the furrow wheel. The rotary cultivator can also be a dangerous implement, for while it certainly crushes and generally disintegrates the old sward, it does the same thing for the soil structure, pulverizing the material out of any natural structure it may have. Further, with the L-shaped blades it can create a cultivation-pan very easily, particularly on the heavier soils on which it is frequently used.

The fragipans referred to occur too

frequently today, and whilst shallow sub-soiling behind the plough does help to some degree, I feel the position needs further consideration.

When utilizing the ley for subsequent arable cropping the vertical integration of the soil profile must be realized. Usually under a good well-managed sward there is a distinctive structural arrangement grading from fine granular and crumb at or near the surface, downwards through progressively coarser and more angular peds. The whole must be regarded as a unit, and whilst it may be sufficient to analyse the top-soil alone for plant nutrients, it would seem that the time is not far distant when the study of the soil profile as a whole will become imperative. For this reason I would suggest, purely at an experimental level, that different cultivation techniques be tried. For example, is it not possible to kill off the sward with a herbicide like dalapon and, after waiting for sufficient leaching to take place, cultivate the soil in a vertical direction only? By this I mean the use of tine cultivators, harrows or similar implements which would only stir the soil sufficiently to form a suitable seed-bed for drilling the following crop. This would mean the reduction in the mechanical breakdown of the aggregates to a minimum and no horizontal break in the profile. Most workers agree that the structure in the top few inches is extremely suitable for a seed-bed, so any system whereby the burial of this soil can be avoided is worthy of trial. Continuing along similar lines, the disc-plough, particularly if the land-wheel of the tractor is kept out of the furrow, is an implement to be considered for it certainly does not create a plough 'sole'. I have virtually no practical evidence for the foregoing statement except some slight experience of using a disc-plough on shallow soils over hard limestone where results exceeded expectations. I must, therefore, emphasize that these last remarks are only hypotheses based on field observations and in no way are they the result of practical experience.

In conclusion, to keep in mind the two-fold aim of good production from the sward and deeper rooting, therefore deeper and more stable structural development, would appear to be of paramount importance in any future research work on grassland and soil structure.

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REVIEWS OF SOME PAPERS READ AT THE 8TH INTERNATIONAL GRASSLAND CONGRESS AT READING, JULY 1960

I. GRASSLAND MANAGEMENT AND ANIMAL PRODUCTION

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A large proportion of the Congress papers were related, either directly or indirectly, to grassland management or to animal production, but I propose to discuss only those which were concerned with *both* grassland management *and* animal production.

At first sight some issues which had been investigated and which were reported, seemed confused, but light dawns when they are considered in relation to McMeekan's edict at the beginning of his paper. This was to the effect that the three basic factors upon which the efficiency of conversion of pasture to animal products depends are:

(1) The amount, quality and seasonality of the pasture crop; (2) The proportion of this crop actually harvested by the animal; (3) The efficiency of conversion within the animal of the fodder consumed.

To quote McMeekan further, "Each of these is affected by grazing management. The selection of the grazing method, the number of animal units employed in harvesting and the kind of animals used in terms of their physiological state and their inherent productive merit, interact not only with each other but with the quantity and quality of pasture feed grown, its seasonality of output, the percentage harvested by stock and the efficiency of conversion to animal products. Overriding all of these, on occasions, is the efficiency of animal husbandry, since poor animal management can nullify completely the benefits of superior grazing systems".

Surely we are all in agreement here. Elsewhere (Ivins *et al.* 1958) I have referred to McMeekan's three points as the grass potential, stocking rate and animal potential, respectively, and as we mean the same I shall continue to use these terms.

At any one time either the grass potential for animal production, stocking rate or animal potential for animal production limits the animal production from grassland and, incidentally, it was the realization of the frequency with which stocking rate and animal potential determine milk yields or liveweight gains from grassland that led me to suggest during the Congress that measurements in terms of yields of digestible organic matter (the amount and quality of the pasture crop as put by McMeekan), might provide a more satisfactory basis for the comparison of some grassland treatments than milk yields or liveweight-gains per acre.

Recalling the discussions which took place at the 7th International Grassland Congress in New Zealand, McMeekan dealt at length with rotational grazing versus set stocking. He quoted the review by Freer (1959) where, in fifteen separate studies throughout the world, rotational systems of one form or another showed to small advantage over set stocking in only two instances. Set stocking was slightly superior in two cases, while results were indefinite or showed no difference in the remaining eleven studies. McMeekan gave fourteen valid reasons why these results came about; some challenged the theories which underlie both systems of management—for example, the evidence of cutting experiments in relation to rest periods and the theory of food reserves—while others criticized experimental design.

In an attempt to resolve some of the issues

debated in New Zealand, McMeekan re-designed the Ruakura experiment designed to compare set stocking with controlled rotational grazing. He incorporated different stocking rates as experimental treatments. The main results from this re-designed trial were that at the lower stocking rate (approx. 1 cow per acre), the differences between set stocking and controlled rotational grazing were negligible in terms of either yield per cow or yield per acre. At the higher stocking rate (approx. 1·3 cows per acre), rotational grazing proved superior to set stocking by some 12%. Further increases in stocking rate led to considerable reductions in yield per cow to the extent that production per acre was reduced.

May I now quote from the paper by Mott on grazing pressure and the measurement of pasture production: "A fixed stocking rate across all treatments in a trial, a practice followed by many investigators, can hardly be expected to measure differences in carrying capacity if such differences result from the treatments. In the grazing trial the investigator is usually concerned with measuring the carrying capacity of the pasture as well as the performance per animal. It then becomes clear that he should be more concerned about stocking the pastures at the same grazing pressure rather than at the same stocking rate. The failure of various investigators to graze their pastures at an equivalent grazing pressure in a large-measure accounts for the lack of more consistent results in studies of grazing management systems. A comparison of a controlled grazing system with uncontrolled grazing may affect the output per animal or the output of herbage per acre. If a fixed stocking rate is used in such studies then only the output per animal is really measured and no measure is obtained of the number of animals which the pasture will support. Having more forage available on a pasture than can be consumed by the livestock is analagous to offering more feed to the animals than they can consume in a dry-lot feeding trial. No one would think of charging the unconsumed feed to the animals in the dry-lot and yet this is precisely what is done in the grazing trial when the pastures are not grazed to their carrying capacity and the animal product is expressed on a unit-area basis".

Bearing this in mind, my interpretation of McMeekan's results is that at the lower stocking rate, where no differences were found between the two grazing systems, the animal potential per acre was the limiting factor and, being the same, imposed the same limit and gave the same result. At the higher stocking rate the grass potential had been exceeded and so had become the limiting factor and here a different limit for the two systems. So, after all, rotational grazing may be superior to set stocking *provided that more stock are brought in to utilize the extra herbage* and the underlying theories may in part be right.

McMeekan's results are yet another example where variability in stocking rate and animal potential can lead us to variability in opinion.

It is now interesting to consider the contribution from Line at the Congress. He had compared rotational grazing with daily strip-grazing over three years at two different rates of stocking with dairy cows. Line found no differences in milk production per cow or per acre between the two systems, but the higher stocking rate gave more milk per acre, which outweighed the loss in yield per cow, presumably due to reduced intake of herbage per cow per day.

This is again a case of similar animal potentials imposing similar limitations, with the result that the two systems gave similar yields. Line's higher stocking rate is on the verge of distinguishing between the two systems and I can only speculate that a still higher stocking rate would have given a different story.

Parallel to this issue is the comparison of "zero" or "mechanical" grazing, or soiling, with systems which permit the animal to graze in the field. Five papers, with a total of 14 authors from five countries, dealt with this comparison. Schechtner (Austria) compared pure soiling with combined soiling and pasturing and found daily milk production per cow to be the same with both methods of utilization. Kennedy *et al.* (U.S.A.) compared

two systems of rotational grazing with strip-grazing and with zero-grazing, and reported that the average production per cow for a 4-year period was essentially the same for all treatments. They suggest that they failed to establish sufficiently high stocking rates to demonstrate that the treatments were different in terms of milk production per acre, but they clearly demonstrated that alfalfa pastures will remain productive for at least three years under a somewhat extensive system of management. Runcie (Great Britain) compared strip-grazing with zero-grazing and did find differences in milk yields, but he associated these with differences in initial yield and did not draw conclusions on the superiority of one system over the other in this respect. Logan *et al.* (Canada) also compared strip-grazing with zero-grazing, over three years. Their results may have been masked by feeding 1 lb. of concentrates per 4 lb. of milk produced, but they conclude that there was no appreciable difference between the two systems of pasture management. Arnon (Israel) described an experiment in progress and, like Runcie, quoted conflicting results from a number of published trials. He emphasized the difficulty of making an objective appraisal of the two different systems when the management practices themselves influence the final results to a considerable degree. This prompts me to ask whether Kennedy *et al.* would have found differences if they had not made strip-grazing the pace-setter? Would Runcie's results have been the same with a different harvesting machine with the herbage cut and fed three times daily?—our experience suggests that in all probability at least the zero-grazed cows would have eaten more herbage. Would Logan *et al.* have had the same results if they had not fed 1 lb. of concentrates per 4 lb. milk? Even after unavoidable variation in cutting dates, where surely Logan *et al.* must have been feeding herbages of different nutritive value, the dairy cows averaged the same milk production.

It is quite clear from all these papers that groups of dairy cows can tolerate a very wide range of grassland treatments, also exercise and environment, with little, if any, effect on *average* yield. We can set-stock them or rotationally-graze them, we can strip-graze them or zero-graze them, and their average milk yields and output per acre are not affected until we increase the rate of stocking. So until we know which system of grass utilization permits highest stocking rates we may never answer the question—"which system is superior"?

The tolerance of groups of dairy cows in terms of *average* yields again prompts me to ask whether grazing trials involving averages of animal production, particularly without differential stocking rates, use a sufficiently sensitive weighbridge to sort out some problems. One might of course ask, if differences cannot be measured in this way, do such differences matter and is not the problem one of relative cost? The superiority of zero-grazing may lie in the facts that roads do not have to be crossed by the herd, the land is not poached, no fencing is required and the gate is not left open on a Sunday afternoon.

Sadar (Yugoslavia) gave a paper in which he reported increased yields of animal products resulting from the adoption of strip-grazing combined with manurial treatment of permanent pasture. A topical point is that his yields of starch equivalent, under the intensive grassland management, were superior to those of fodder crops, including maize, for silage.

Pigden and Greenshields (Canada) described trials which were conducted with grazing beef cattle at five widely separated stations in Canada. Using different experimental designs—some with continuous grazing, others rotationally grazed—they found interactions between liveweight gains and dry-matter consumption, between stations and between designs within stations. More dry matter per pound gain was required in the continuous grazing experiment than in the rotationally grazed design.

The effect of selective grazing on animal output was discussed by Blaser *et al.* (U.S.A.) Systems of top-, bottom- and whole-plant grazing management were imposed to give varying degrees of selective grazing. Milk production per cow was much higher for top- than for bottom-grazing on lucerne/cocksfoot

swards, the followers consuming herbage lower in protein, fat and digestibility than the top-grazers. Steers grazing the tops of plants gained 20% more than those forced to graze the whole plant, which in turn gained 20% more than those restricted to bottom-grazing. These results are of importance in relation to grazing systems and particularly rates of stocking in experimentation.

Possibly the private discussions at the Congress proved more vigorous than the discussions in public. Here I am bringing more discussion into the open and in reviewing these papers I have been critical on purpose. To me they illustrate the great need for the fullest information when the results of grazing trials are reported. Then we can see more clearly whether the grass potential or the animal potential is likely to be responsible for the results.

Which system of grazing management dare we advocate in view of these indefinite results? Clearly we must produce the feed per acre and so species, varieties, manuring, etc. are still vital factors. Having produced the feed it must be eaten and digested, and then the milk or beef depends mainly on the animal. Unfortunately the grazing system, if any, which produces most digestible feed per acre has not been ascertained in these trials reported at the Congress. A revolution in techniques may be necessary before the answer is clear.

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II. Grass and animal nutrition

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To all intents and purposes the only important consumers of grass in many countries are now ruminants, and in consequence the Congress gave a great deal of attention to the part grass plays in the nutrition of the ruminant and to the ways in which the value of swards for this purpose can be measured. There were also most useful discussions about some of the disorders which may be encountered when high levels of grass are used in the nutrition of ruminants, but there will not be time to say anything about these disorders here.

I propose to try to show how the contributions answered some of the questions which face us when we attempt to assess the value of grass as an animal food. The first question is, perhaps:

How can the nutritive value of grass be measured?

For too long the agronomist measured grass output as dry matter and crude protein per acre and the nutritionist said that these terms had little use in predicting the value of the swards for animals. To be fair to the agronomist it must be understood that he received no clear recommendation about more useful units. The discussion this year showed a very much improved situation.

Those who are interested in growing and preserving grass now seem increasingly prepared to express their results as digestible dry matter or organic matter per acre. They are now searching for rapid methods for determining these units. At the same time the nutritionist is being pressed to comment on the significance of the units as estimates of nutritive value. It was satisfactory that the sessions should provide some answers to these questions. Let us begin with methods of determining digestibility.

Methods of determining digestibility

Dr. Kivimäe (Uppsala, Sweden) was the only worker to report an attempt to relate digestibility to chemical composition. In red clover the digestibility of organic matter was estimated best by lignin and crude fibre, followed by protein and methoxyl; with timothy, methoxyl and lignin gave the best estimate. It appears that with these pure crops the standard deviation of individual determinations from the regressions was about $\pm$ 2 units of digestibility. It is clear that to establish suitable relationships for a wide range of crop plants, and to be sure that under varying conditions these would hold good even within much wider limits, would be a tremendous task, the value of which is still open to doubt.

Rapid methods for determining digestibility have been sought in the use of the *in vitro* rumen technique, especially in the United States. Shelton and Reid (West Virginia University) reviewed the numerous attempts which have been made to use this technique to obtain a quick indication of the digestibility of a forage. They reported that high correlations have been demonstrated between digestibility coefficients determined *in vitro* and corresponding values obtained with cattle or sheep in conventional digestibility trials. These authors pressed for standardization of technique.

From Hurley, Tilley, Deriaz and Terry also had favourable results to report. They have

been using an *in vitro* technique in which the herbage is initially fermented anaerobically for 48 hours with rumen liquor. The novel feature of this method is that this fermentation stage is followed by an acid pepsin stage, also lasting for 48 hours. Values obtained by this double procedure were reasonably reproducible (S.E. ± 2–3) and reasonably close to values obtained with sheep. In an investigation of 20 samples, the standard error of estimate was ± 2 units of digestibility. While the authors appreciated that a difference of 6 digestibility units would be necessary to achieve significance, they point out that even estimates obtained with animals are subject to variation due to the age of the animal, the level of feeding and the species fed. It was wisely suggested that the technique might be used to determine *in vitro* digestibility values under specified conditions, rather than to predict what the digestibility would be in an animal at some particular level of feeding.

Perhaps the greatest merit of these *in vitro* techniques would lie in their value for screening large numbers of samples and in the fact that the amount of material required is very small. Since their use must always depend on arbitrary decisions, e.g. on the length of the incubation period, the values obtained would be more acceptable if they were designated by some new term; *in vitro* breakdown value (I.V.B. value) could be suggested but at present this would have to be qualified by a reference to the method, e.g. I.V.B. value (Tilley, Deriaz and Terry, 1960).

What are the factors determining the digestibility of grass?

For many years, lip-service had been paid to the obvious fact that the digestibility of pasture plants decreases with advancing stage of growth. Reports from Norway and the United States suggested that this fall was much less haphazard than had been supposed. Minson, Raymond and Harris (Grassland Research Institute, Hurley) presented the results of a most detailed study of three strains extending over the highly contrasting summers of 1958 and 1959. It was shown that in S23 ryegrass (late flowering), S24 ryegrass (earlier flowering) and S37 cocksfoot, the rate of decline in the content of digestible organic matter in the herbage dry matter (called **D**) followed markedly different patterns. The relationship between the patterns remained remarkably similar in both years. The date at which the decline began appeared to be related to the time of ear emergence.

An investigation of the digestibility of regrowths, cut at monthly intervals, was also made. Here again there was a marked similarity between the patterns for the two years. With both first cuts and regrowths the cocksfoot had a lower digestibility at any cutting date than either ryegrass. The authors have concluded that systematic studies of the yields and digestibilities of various herbage species and varieties, such as the investigation described here, and the logical relation of herbage nutritive value to species, stage of growth and environment should lead to results of direct use to both the scientist and the farmer. These conclusions are justified by the order which these experiments have brought to a subject which was previously highly confused. For some purposes it may well prove possible to compute the digestibility of crops of known strains from the date on which they were cut. This is already being used for advisory purposes in the U.S.A. I think it should be pointed out that these results alone have justified the decision to build at Hurley large, and undoubtedly costly, cold storage rooms and really extensive facilities for digestion trials. They show the return which can be got from whole-hearted support for a principle which is basically sound; a half-hearted approach might well have added to the confusion.

We were reminded by Milford (C.S.I.R.O., Queensland) that in subtropical areas, the problems encountered in pasture evaluation are rather different from those encountered in temperate zones. But here again the digestibility trial had proved most useful in providing a practical unit of nutritive value. Further, with a number of subtropical species, the voluntary intake of the herbage has proved to be closely linked to the percentage digestibility of the dry matter.

There was, accordingly, a general feeling among the speakers at the Congress that the determination of yields of digestible dry matter, or of digestible organic matter, per acre was a feasible means of expressing the nutritive value of a pasture. This point was most forcefully developed by Ivins who submitted that, in the evaluation of pastures, total quantities of digestible organic matter and its constituents are a more valid assessment of pasture values than figures for animal production. A few years ago it would have been expected that the results of all these digestibility trials would have been used, with the aid of various factors, to calculate a value for the net energy of the roughages concerned. This would probably have been expressed as starch equivalent. It was noteworthy that there was no such attempt in any of the papers. It is pertinent to ask, accordingly, what the contributions added to our knowledge of the relationship between, for example, digestible organic matter and net energy.

What is the value to the animal of the products of digestion?

There were several contributions which reflected the anxiety we must all share lest the value of any system of assessing nutritive value in units of digestible dry matter or digestible organic matter should depend almost entirely on the mere assumption that there is some general relationship between these units and the net energy of the foods. Several papers dealt with aspects of this question and of the related problem of the nutritive value of the products, especially volatile fatty acids, produced during fermentation in the rumen.

The digestion of herbage obviously depends largely on the action of the flora in the reticulo-rumen and it was apt that the programme included an excellent account from Bryant (Beltsville, U.S.A.) of the ways in which study of the metabolism of pure cultures of ruminal organisms can further understanding of the problem. Knowledge of the metabolism of individual species cannot at present be related quantitatively to the sum of the metabolism of many species in the rumen. It is clearly necessary, however, to have knowledge of the substrates attacked and of the products of attack by the individual species if ever we are to be able to predict what will be the end products of fermentation in the rumen, or indeed *in vitro*.

Predicting what will be the end products of fermentation in the rumen may become an important task for students of ruminant nutrition. In a report from Shinfield we pointed out (Balch, National Institute for Research in Dairying) that even with a group of diets supplying the same theoretical starch equivalent, considerable differences may be found in the proportions of the individual volatile fatty acids produced in the rumen. Large changes in the proportions of acetic and propionic acids can be brought about by preparing the food in certain ways, and these do not necessarily require changes in the amounts of the components of a diet, although changes in the proportions of the components will in themselves affect the mixture of acids. We were able to refer to a small amount of evidence to show that, through the grazing season, the mixture of acids found in sheep varies almost as much as, in cows, with extremes of indoor feeding. It was, therefore, a happy coincidence that in the second half of the next paper Tilley, Deriaz and Terry discussed the mixtures obtained in sheep receiving a wide variety of herbages; here again there was a wide range in the proportions of the various volatile fatty acids found in the rumen. There is a great need for a means of predicting these proportions, and their relationship to the concentration of digestible organic matter in the dry matter might repay study.

In his paper Blaxter (Hannah Dairy Research Institute) reviewed the important series of experiments at Ayr showing that such differences in the proportions of the acids may not have much effect on the energy value of the total mixture below maintenance. They will however have a marked effect on the value above maintenance, since for lipogenesis the value of the acids increased with increasing chain length. When, in experiments at

Shinfield, individual acids were infused into the rumen of milking cows receiving normal diets of hay and concentrates, the individual acids appeared to have both general and specific roles in milk secretion. For example, acetate appeared to have a general effect in increasing the yield of milk and of each constituent; acetate appeared to have an additional specific effect in raising milk-fat percentage, and propionate had specific effects in lowering milk fat percentage and raising the solids-not-fat percentage.

These complexities naturally leave us wondering whether digestible dry matter or digestible organic matter is going to prove a suitable index of the nutritive value of grasses. From the Hannah Institute, Armstrong reported on determinations of the net energy of ryegrass at four stages of growth. The ratio of metabolizable energy to digested energy did not change with increasing maturity of the grass, although it narrowed when intake increased. The net availability of metabolizable energy for maintenance was constant for all four cuts, but above maintenance the availability was higher in earlier cuts than in later cuts. It was concluded that to define an optimal cutting stage the intake of food must be known, in order to assess the proportion of the food energy used for maintenance.

Here then was a further complication to the concept of a simple measure of nutritive value. The paper by Blaxter was an analysis of all the complications. It was pointed out that some of the factors which determine the energy retention of an animal can be referred to the food given and some to attributes of the animal. The management, level of feeding and the environment all have to be considered, as do various interactions such as those between the voluntary intake of the animal and its maintenance cost, between heat loss and the fermentation pattern in the rumen and between resistance to cold and food intake. It seemed to be asking rather a lot to expect a single determination of the apparent digestibility of a grass product to provide the basis for a prediction of animal performance in such a complex situation. Yet, Dr. Blaxter concluded, from the results obtained with grassland products, it appears that, provided digestibility coefficients are interpreted in relation to knowledge of the overall energy exchange of the animal, they have more than an academic utility. When more calorimetric data have accumulated, it may be possible to predict with moderate precision the net energy value of a food from its digestibility coefficient determined at a particular nutritional level. This must have been a most encouraging statement for those who have been busy getting information about digestibility, but we must bear in mind that respiration studies take a great deal of time and effort, and so far this relationship between digestibility and net energy has been tested with very few forages.

I need not emphasize here the danger that we go to a great deal of trouble to measure the nutritive value of a forage only to find that the animals will not eat as much of it as we would wish.

How can we measure the voluntary intake of roughages by animals?

Several speakers touched on this problem and I have previously mentioned the observations of Milford. Blaxter also produced estimates of the extent to which the voluntary intake of highly digestible roughages exceeds that of less digestible materials. There now seems little doubt that this is related in some way to the fact that such foods cause different degrees of distension of the gut.

This concept has been explored recently in Canada. From Crampton, Donefer and Lloyd (Macdonald College), we heard a description of the theory that a satisfactory index of the nutritive value of a forage must comprise estimates of both the amount that will be voluntarily eaten and of the digestibility of the energy. It is proposed that the value of a food should be expressed as a Nutritive Value Index (N.V.I.) incorporating both these properties of the food. Since the voluntary intake appears to be related to the digestibility, it may suffice to determine the digestibility. Crampton and his colleagues in fact proposed tentative constants for a relationship which enables the N.V.I. of a forage to be calculated simply on the amount of cellulose broken

down in a 12-hour *in vitro* fermentation with rumen contents. It may be argued that it would not always be convenient to have the estimate of the nutritive value of a food confused with an estimate of its acceptability. This does illustrate, however, yet another use to which people are thinking of putting digestibility coefficients and of a practical use which may one day be made of a standardized *in vitro* technique.

CONCLUSION

The papers I have described lead one accordingly to the conclusion that if those who study methods of growing grass express their results as amounts of digestible organic matter or digestible dry matter there is a good chance that these units will prove meaningful to those who require an estimate of the energy value of the grass. It is not hard to see how such units might be used in advisory work.

This simple picture is too optimistic. The measurement of the nutritive value of grass is now certainly much more orderly than before. But I wish to close on a note of caution. A significant relationship between breakdown *in vitro* and digestibility in sheep may perhaps be demonstrated by using a conveniently wide range of foods. But, as Mr. Raymond pointed out in discussion at the Congress, it does not follow that the errors will be small enough—or at least small enough in everyone's hands—to give sufficient accuracy even for advisory work. The magnitude of the errors in these estimates, and especially of differences between workers and between laboratories, must be very small before the *in vitro* technique can become more than a useful aid in research. The need for large-scale facilities for carrying out digestibility trials with sheep has certainly been increased by the information presented at the Congress. For this particular purpose it may well prove a better investment to get results with sheep rather than to spend time developing an *in vitro* technique.

I mentioned the need to predict the mixture of volatile fatty acids which will be produced when a forage is fermented in the rumen. We have seen that a change in the proportions of a mixture will not affect the value of the mixture for maintenance, but will change its value for lipogenesis and may well change the amount of milk, or of one or more of the constituents of milk, secreted. It is already clear that as the digestibility of a crop changes, the proportions and amounts of the volatile fatty acids change. If we are ever to have confidence in some single unit, it is imperative, therefore, that we should know more about the relationship between digestibility and the proportions of the acids, and about the extent to which the effects of changes in the proportions are masked or exaggerated by changes in the total amount produced.

III. PRACTICAL IMPLICATIONS OF 8TH INTERNATIONAL GRASSLAND CONGRESS

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The International Grassland Congress is a scientific congress dealing mainly with fundamental problems, techniques of research work and so forth. Many of us who are not scientists are very glad to be able to attend and, whilst we do not expect to hear farming papers as such, the range of the papers is so wide that they include a good number that can be considered as being at the practical level. There are sufficient of these to justify the purchase of the Proceeding of the 8th Congress by any practical man, and I think it can be considered as providing an up-to-date review of information and thinking on all aspects of grassland work.

Congress members from overseas visited many farms privately and during pre-Congress tours, and I think it is quite proper for me to draw on the impressions gained from discussions on the farm and elsewhere, in addition to material from Congress papers.

It would be no exaggeration to say that at the practical level the papers and these exchanges raised as many doubts as they solved. That is not surprising with such a new subject as grassland management in the modern sense. We build up our knowledge and experience by continually encountering new problems and gradually working through them.

The present tendency towards over-supplied markets, which we are meeting with so many of out livestock products, raises the important question as to whether we are justified in raising output from our grassland. Leaving aside for the moment any cheapening of production costs by better use of grass, it seems inevitable that improvement of grassland will give increased total production.

In his plenary paper, Melville of South Australia reminded us that the world population of 2600 millions in 1960 is expected to increase to 3600 millions by 1980, with a likelihood of 5000 million by the end of the century. He pointed out that only 25% of present world population is adequately fed. Melville stated that whilst this background was familiar to every member of the audience, he reiterated it because it formed the basic framework with which the members of the Congress as members of an international body must assess their efforts to increase the efficiency of world animal production. I suggest that the same background provides strong justification for maximum improvement in our grassland management techniques, thereby achieving cheaper production of livestock products and increased output. W. J. Thomas of Manchester dealt with economic aspects of grassland production and utilization. He mentioned many aspects of this complex subject, but one of his conclusions was to the effect that grass grazed *in situ* is the cheapest of all feeds, and that where the prices of livestock products are low, grassland often becomes virtually the only possible basis for livestock farming. With conserved grass the unit costs are much closer to other farm crops. He pointed out that whilst it is technically possible to raise the yields of other farm crops, most farmers already farm their arable crops at a higher level than their grassland, so that with grassland products there is more scope for improvement.

Dr. William Davies gave an admirable review of the present state of productivity of British grassland. He pointed out that the grassland and pastoral areas of the world provide the most important single item of ruminant feed. He stated also that the potential for increased animal production from grassland in both tropical and temperate regions is substantial. He pointed out that the meat and

milk producing ruminant must play a leading role in the world economy of the future, but we must keep an open mind regarding alternative foods offered us by the biochemist. If meat and milk are to fill this role, then grassland improvement must be a first essential, because the economy of animal production depends largely on the full and proper exploitation of grass. Dr. Davies called attention to the present poor utilization of much of the grass produced, and finally gave a table indicating that, taking the output of U.K. grasslands for 1960 as 100, the relative output in 1940 was 41. The potential output for 1980 was given as 340.

The Congress speakers' views that I have mentioned up to this point have been connected with the natural anxiety of the practical man as to whether he will, by improvement of his grassland, bring about such a surplus of livestock products as to glut his market to an extent that prices become uneconomic. There seems to be reason for believing that the additional output will be required and that there is ample scope for achieving it.

My mention of these papers has to be so brief that I run a serious risk of quoting some of the conclusions out of context. I hope, however, that I have given reasonably fair interpretation of some of the views expressed.

Before leaving Dr. Davies's paper, I would like to refer to the perplexing question of white clover as a source of nitrogen, particularly in areas of moderate or low rainfalls. Perhaps by reason of the drought of 1959 and the dry spring and early summer of 1960, the white-clover content of many of our pastures was particularly low at the time of Congress visits to farms. Those of us who went to New Zealand in 1956 knew full well what the reaction of our New Zealand and Australian visitors would be. At their earlier visits we had to submit to much caustic comment about our inability to combine high yields of grass with the desirable level of white clover.

Many of us have been driven to the conclusion that in the absence of irrigation or high rainfall it is almost impossible to maintain a desirable level of white clover, once productivity has been pushed up to or beyond the region of 7000 lb. dry matter per acre. There was a great deal of discussion and argument with our visitors, none of which helped us much, and overseas scientists visiting my own farm shortly before leaving for home agreed that we seemed to have no option but to put on nitrogen if we wanted high yields. Some of them were doubtful whether white clover was the best legume at this level of output. In the light of our experiences of the difficulties of maintaining white clover at satisfactory levels in association with really high yields, and in the light of the potential grassland yields he quoted and the levels of nitrogen he mentioned as being necessary to get those yields, I was a bit surprised that Dr. Davies should state, "Recent work suggests strongly that the ryegrass/white clover community is amongst the most productive of the grassland communities in Britain. It is also easy to establish, easy to farm and not difficult to maintain at high production". These last few words were the ones that surprised me. It is my own experience that if really high production is maintained the sward ceases to deserve the description ryegrass/white clover.

The subject was dealt with in detail by Green and Cowling, of Hurley. They expressed the view that dependence on nitrogen fixed by white clover may limit production to 5000/6000 lb. dry matter per acre, whereas a grass sward under similar conditions, but given adequate nitrogen, may yield twice this amount. They left me with the impression that to get the 5000/6000 lb. level a high standard of management is required, leaving little flexibility or scope for meeting the varying needs of the animal or the conservation programme. They pointed out that yields of 5000/6000 lb. dry matter are well above the average yield of grassland in the U.K., but many of us, particularly if we farm limited acreages, are thinking in terms of 7000 and beyond. It seems clear that at this level the harnessing of white-clover nitrogen is most elusive.

The guidance forthcoming as to optimum application of phosphate and potash in given circumstances was disappointing. Dr. William Davies gave a timely warning that some of us may be using phosphates and potash too liberally. Excess of phosphates is merely

wasteful, but excess potash can be dangerous, especially as regards the metabolism of the grazing animal. Most of us are now aware of this danger. On my own farm we no longer find any response to trial strips of extra phosphate or potash, even in conjunction with high nitrogen usage. This suggested that basic deficiencies had been corrected and we had been thinking of reducing slightly from past levels of around 50 lb. P_2O_5 and 72 lb. K_2O per year. Before doing so we submitted soil samples from several fields and were puzzled to get reports of 'very low' and 'markedly deficient' in both phosphates and potash on a number of the samples. In his paper Dr. Davies suggested 30 lb. phosphate and 25 lb. potash as maximum annual dressings when basic deficiencies had been corrected. He may be right, judging by the lack of response on our trial strips at home, but how do we reconcile all this with the results of the soil analyses?

Time does not permit of my doing justice to Dr. McMeekan's plenary paper on Grazing Management. The "practical implications" of the paper are of the highest order and it helps tremendously in putting into perspective the interactions and intricacies of this very complex subject. The best advice I can give is to study the paper. I will attempt to comment on an aspect of grazing management that has puzzled so many of us and which Dr. McMeekan has helped to clear up—it is this. A high proportion of the food consumed by the grazing animal is used for maintenance and so becomes a type of overhead charge. Because of this, it has seemed sensible to get the highest possible "production" from that animal (particularly if it was a dairy cow) in order that the maintenance overheads should be spread over as many "production units" as possible. Applied to grazing management, that meant that the intensity of stocking tended to be geared to the highest possible "production level". It seemed illogical, therefore, when we were told that the heavier stocking, at the cost of some falling off of "production level" of individual animals, would result in greater net production per acre, despite the greater amounts used for maintenance.

Dr. McMeekan has stated that the three basic factors from which the efficiency of conversion of pasture to animal products depends are:

(1) The amount, quality and seasonality of the pasture crop.
(2) The proportion of this crop actually harvested by the animal.
(3) The efficiency of conversion within the animal of the fodder consumed.

It seems likely that No. 2 of these, the proportion of the crop actually harvested by the animal, is the main reason why higher net production is obtained from heavier stocking. In trying to gear our stocking to the highest possible "production level" (particularly if our heaviest yielding dairy cows were considered) we probably stocked too lightly for the most efficient harvesting of the grass by the animals, and we also fed the lower yielders somewhat extravagantly.

McMeekan shewed, and it is obvious, that the policy of heavier stocking can be pushed beyond "optimum", but it seems likely that many of us have been a bit too liberal in the area or quantity of grass allowed to our cattle. It follows that "production" output per acre per year can often be increased by tighter stocking. This can be done without going too far in the direction of defoliating too often or too severely.

Under U.K. conditions, where such a substantial proportion of the grass crop is required for conservation, "heavier stocking" will often mean carrying on with the same number of cattle, but using more of the available grass for conservation with consequent lowering of winter-feed costs. In some cases it will mean release of acres for cash crops.

Amongst the many factors affecting growth and production from pastures reviewed by McMeekan, "light availability and intensity" was mentioned, and the importance of light to growth is a subject about which very little is known at the practical level. As farmers, we should attempt to get such knowledge as we can, as light availability is so much affected by the density and height of the crop. This subject was dealt with by Shain of the U.S.S.R.

The differences of opinion as to the respective merits of strip grazing, rotational grazing and set stocking that we have heard in this country were evident during the Congress. Sadar of Yugoslavia reported highest yields from rationed strip grazing. Line of Shinfield reported that a comparison of daily strip folding and a system of rotational grazing when fresh pasture was allowed every 4–7 days shewed no difference between these two systems. Blaser and other workers at Blacksburg, Virginia, had demonstrated the substantial difference in milk yield and liveweight gain between systems of top-, bottom- and whole-plant grazing. This work was discussed in connection with experimentation, but it appears to demonstrate the advantage of strip grazing as a means of ensuring whole-plant grazing and thereby avoiding large variations in the diet from day to day. It also points to the possible merit of letting heavy-yielding dairy cows graze ahead of the lower yielders. Mott of Indiana discussed the effect of stocking rates in connection with experimental procedures; his paper was interesting to the practical man in the way it demonstrated the extent to which production could be adversely affected by undergrazing as well as by overgrazing. I am left with the impression that there is little to choose between efficient rotational grazing and strip grazing. When it comes to set stocking, a high degree of judgement is required and the system probably has more application to the prostrate type of pasture grass, such as S23.

Holmes and Sykes of Wye College reviewed the response and profitability of feeding concentrates to dairy cows in summer. They shewed that, apart from special needs, (such as a continuation of winter feeding into April, the use of concentrates as a convenient means of administering magnesium oxide, or for the steaming-up of autumn-calving cows), no worth-while increase in milk yields or composition is to be obtained from the feeding of concentrates as long as good enough quality grazing is available. They found also that high stocking rates were associated closely with high profitability and high Utilized Starch Equivalent per acre.

Papers on zero grazing were given by workers from Austria, U.S.A., Scotland, Israel and Canada. Generally speaking, the experiments and experiences reported shewed no very wide differences of yield per cow or per acre between zero grazing and traditional grazing. The papers left the impression that the case for zero grazing rested in the main on the type of forage used and the existence or otherwise of physical difficulties in following normal grazing practice.

Professor Morrison of Hillsborough reviewed recent developments in the production and feeding of grass silage. He stated that a compelling reason for silage making is its usefulness in grassland management. Mention was made of the value of a covered silo, particularly in high-rainfall areas, but he concluded that there is no great case for the use of metabisulphite in the ensiling of grass on the average farm. Wilting was shewn to have value in the ensiling of young sappy material, but attention was called to the need for careful control of silo temperatures and the timing of field operations. Severe wilting, extending beyond 24 hours in the field, can give rise to significant dry-matter loss. Many advantages were said to follow the use of the forage harvester. At Hillsborough, silage has been fed to beef cattle over a period of 10 years with most successful results.

A comparison of AIV silage and tripod hay fed to dairy cows, reported by Larsen of Denmark, resulted in the conclusion that, in Denmark, silage making should be increased at the expense of haymaking.

Murdoch of Shinfield shewed that low temperatures in silage making have no adverse effect on fermentation where conditions favour a desirable fermentation.

Shepperson of Silsoe reviewed haymaking methods and shewed the extent to which methods such as barn hay-drying, rack- or tripod-drying, have particular value when normal drying conditions are not of the best.

The papers of Morrison, Murdoch and Shepperson are worth study as an up-to-date review of silage and hay conservation.

Closely linked with conservation as regards the optimum time of cutting is the work at Hurley described in the paper by Minson,

Raymond and Harris. It seems clear that their work on digestibility of grass species will provide information that will be of the greatest assistance to farmers in arranging grazing, and the cutting of grass for conservation at periods of optimum feeding value.

In addition to various Conference papers on the subject, Seekles of Holland gave a plenary paper entitled "Aspects of physiological disorders in grazing livestock". He shewed how extremely difficult it is to relate physiological disturbances to grazing conditions. I was left with the impression that, beyond those aspects of the subject already known to U.K. farmers, very little emerged that has immediate application at the practical level.

Evaluation of grassland output was dealt with by Professor Ivins and various other speakers, but primarily in connection with accurate evaluation for experimental purposes rather than farm recording.

I fear that this has been a very sketchy and incomplete review of the practical implications of the Congress, but I believe it will shew the wide range of subjects covered and the information to be obtained from the published Proceedings of the Congress.

WATSON, S. J. and NASH, M. J. **The conservation of grass and forage crops.** 2nd edn., 1960, pp. xiv+758, bibl. 697–746, 25×16 cm., Edinburgh and London: Oliver and Boyd, 84*s*.

There can be little doubt that the livestock industry in the United Kingdom falls short of its potential each year owing to the failure of many farmers to appreciate fully the many scientific principles governing the efficient conservation of grass and fodder crops. This is due partly to the small scope of many of the experiments on hay- and silage-making, and partly to lack of consistency and clarity in advice on these processes.

There can also be no doubt that Professor S. J. Watson, both in his original experimental work at Jealotts Hill and Edinburgh, and also in his voracious search of the world literature over many years has done far more than any other to elucidate the principles and to point the way to more efficient methods of conservation.

In this second edition, in collaboration with Dr. M. J. Nash, Professor Watson has rearranged, rewritten and brought up-to-date the material of the two volumes of the first edition, and presented it as a single large volume divided into: Part I. Natural and artificial drying; Part II. Ensilage, and Part III. Utilization of dried and ensiled crops. The result is an authoritative text book and since it is provided with a full list of contents, bibliography and index, it will form a standard reference book for those who are concerned with technical aspects of grass and forage crops and their utilization.

Although a substantial proportion of the 2000 references given concern papers that have appeared since the first edition in 1939, it is of interest that the authors found no reason to make any major changes in the conclusions of the first edition. In the case of silage making, one reason for the absence of change in the basic method, as originally envisaged by Professor Watson, lies in the fact that it is difficult to assail it on economic grounds. Rapid establishment of the correct acidity by controlling the stage of maturity of the crop, control of moisture content of the crop when harvested, laceration, compression, etc. have, for one reason or another remained relatively inexpensive and in the last two decades these methods have not been seriously challenged by new additives or new systems of conservation. It is, however, by no means easy to give a simple statement of the correct method of ensiling for the typical dairy farmer who nowadays is often provided with a 'self-feed' silo and a flail type forage harvester. To him, both quantity and quality of silage may be of great economic importance. Should he wilt his grass? This will involve an extra field operation and may increase field losses. The answer is perhaps a compromise, for the value of wilting may be very great at the bottom of the silo but may actually be detrimental in the top layers. Should he use an additive? This also may depend on the condition of the grass. The young valuable sward may lack carbohydrate to promote a good fermentation and in this case molasses may be of great value. At a later stage of maturity there may be sufficient carbohydrate in the sward, and bruising by the flails may make this available at a sufficiently early stage to allow the production of lactic acid and suppress undesirable fermentation. Should he roll the silage with his tractor? This again depends on the dry-matter content of the grass, the rate of filling, rate of temperature rise, etc.

The best advice that can be given to the practical silage maker, therefore, is to try to learn something of the processes involved and there can be no better way of doing this than by reading the appropriate sections of this new book. He will probably be saddened by the lack of pictorial illustration, but the text is not beyond the scope of those with a modest knowledge of chemistry.

The biochemist may be a little disappointed that on the utilization aspect little effort has been made to weld into the text the newer findings of the rumen biologist. Nevertheless, for these and for most classes of readers the book will remain a valuable source of guidance for many years.—A. S. Foot. From *Herbage Abstracts*.

BOR, N. L. **The grasses of Burma, Ceylon, India and Pakistan (excluding Bambuseae).** 1960, pp. xviii+767, bibl. 567, illus., 25×16 cm., Oxford, London, New York, Paris: Pergamon Press, £8.

The last comprehensive work on this subject, the seventh volume of Sir Joseph Hooker's *Flora of British India*, was published in 1896. So much knowledge has accumulated in the interval that a book by a single author on the grasses of the Indian region must rank as a considerable achievement. It is the result of 30 years continuous study and has been compiled with great care. But complete finality in botanical nomenclature is not attainable, and there will be general satisfaction that the book is now published.

Dr. Bor has recently retired from the post of Assistant Director of the Royal Botanic Gardens, Kew, and was formerly a member of the Indian Forest Service. The Director of the Royal Botanic Gardens, Dr. George Taylor, has written a foreword.

The book opens with a short general introduction, occupying 60 pages, which contains four chapters dealing with the morphology of the grass plant, the dispersal of fruits and seeds, uses of grasses, and obnoxious grasses (including weeds). It is odd, to say the least, to have a chapter on morphology without illustrations. Presumably space was too precious. But the written statement is a very clear one, and the many examples quoted help to slot the important groupings into place. Much valuable information on food and fodder, essential oils, paper making, and the like, is

presented in the same concise manner. The absence of any map of the Indian region is most disappointing, even though this is not a book on ecology. When writing of grasslands the author accepts the view (put forward by others) that "in India the climate is either a forest climate or a desert climate", so that no tracts of natural grassland exist to be mapped. All grass is secondary, or nearly all. This is an interesting view, but some will think it extreme.

The systematic part, which is the main body of the book, lists more than 1200 grass species. The author follows Robert Brown in dividing the family into *Panicoideae* and *Pooideae* on spikelet characters. Thereafter the tribes within each section, genera within tribes, and species within genera, are set out in alphabetical order. Dichotomous keys to the genera and species are provided. It is suggested, very reasonably, that so long as much remains in doubt about the phylogenetic relationships of the grasses this utilitarian arrangement is as good as any other. The *Panicoideae* with 3 tribes, and the *Pooideae* with 36, are nearly equal in strength, because the tribes *Andropogoneae* and *Paniceae* in the former section account for more than 40% of all the material. The full synonymy of each species is given, followed by its distribution, general notes where appropriate, and chromosome number where known. Formal Latin descriptions of new tribes, genera, species and hybrids are included in an appendix.

The large clear type makes easy reading and the drawings are excellently reproduced. Inevitably in a book of this kind there are some typographical errors. La Cour found 36 chromosomes in *Pennisetum clandestinum*, not 26 (p. 344), and the serial numbering of the species has become confused on p. 95 and pp. 455–6. The bibliography lists about 600 references. The index is confined to taxa and is mainly useful for tracing synonyms.

Without doubt this book should be placed in every botanical and agricultural library. Its interest will be world-wide and in no way confined to the region it describes. However, its price will put it beyond the reach of individuals who are not either wealthy or very devoted agrostologists. Keen disappointment on this score will be felt by those who received the preliminary notice in which the price was given as 80s. —J. D. JAMESON. From *Herbage Abstracts*.

DAVIES, W. **The grass crop, its development, use and maintenance.** 2nd revised edition, 1960, pp. xv+363, bibl. 853, illus., 13·5×21 cm., London: E. and F. N. Spon Ltd., 45*s*.

This second edition of Dr. Davies' well-known book is as eminently readable as was the first. The two opening chapters, the second of which is an addition to the original book, set the stage and introduce the reader to the author's concept of the grass crop and the farming systems of which it is an integral part. In the next four chapters is developed the thesis of the grass crop as a phase in the ecological succession, and one that must be clearly recognized as being a phase the equilibrium of which can easily be upset. These are fascinating chapters and should be read by all who have any connection with agriculture, scientific or practical, as well as anyone with an interest in the countryside, since grass occupies more than three-quarters of the total land in agricultural use in the United Kingdom.

If grass is to be maintained at its best, then the relationship between grass itself, the soil on which it grows, and the animals feeding on it must be clearly understood and this is the theme the author has developed throughout the book. The grass crop, it will be realized, does not refer to grasses alone but to the associations of grasses, legumes and other plants that all go to make up the grazed areas of the world.

The types of British grassland are next described and this leads to a discussion of permanent grassland and marginal and hill lands. The point is made that these tend to move towards the ecological climax, which is woodland and forest, and away from the desired grassland phase, normally linked in British agriculture with an arable phase. From this we pass naturally to the ley, a subject that takes up five chapters starting with a historical account of its origin, and dealing fully with its establishment. It is emphasized that the ley is a farm crop and an integral part of the rotation of the well-managed farm. The effect of the ley on soil fertility is all-important and it is suggested that the very short ley may not produce the desired results and that a period of three years under a ley may be necessary.

The practical approach of the author is obvious throughout, and this may be exemplified by his acceptance of the fact that the ley must often suffer from witting gross mismanagement by the farmer in the interest of his livestock. Equally it is emphasized that, in general, the grass crop is ill-farmed and requires skill in management and skill in maintenance. The contribution that the ley could make to British agriculture is not generally realized and it is claimed that our grassland productivity could easily be doubled if permanent grassland were replaced.

To get such results, proper nutrition of the sward is essential, and all possible steps must be taken to extend the grazing season; these aspects occupy the next two chapters.

In the chapters on seeds mixtures and the production of herbage seeds, particularly the latter, Dr. Davies shows a detailed knowledge of the subject that will be of the greatest value to the producer.

Lucerne, a crop that has not really been taken up by the British farmer, though Dr. Davies can see no reason for this, is the subject of a chapter as also are grassland herbs, though these last do not here receive the emphasis that was accorded to them by early grassland workers.

In the final chapters the author again underlines his philosophy of grass as a crop and thus rounds off a most enjoyable book. In comparison with the first edition Dr. Davies can now quote results from the Grassland Research Institute, the station that he himself directs, which show how much is being done by his staff and by himself to answer some of the many questions which still need to be answered, many of which are put so clearly before us in "*The Grass Crop*".—S. J. WATSON. From *Herbage Abstracts*.

ELWELL, F. R. **Science and the farmer.** 1961, pp. 188, 19×12 cm., London: E. Bell and Sons Ltd., 15s.

Miss Elwell's book is written for boys and girls interested in farming. Written in the form of a story, the book gives a number of examples of how science has influenced agriculture. The average young reader should absorb a great deal of useful information from it.—D. W. COWLING.

EDDOWES, M. and HARRIS, R. **Measuring output from grassland in terms of amimal production.** *Tech. Bull. 5 Harper Adams agric. Coll.* 1961, pp. 21, bibl. 9, 3s. 6d. [Newport, Shropshire]

Three methods for measuring grassland output in terms of animal production, (a) cow-equivalent days, (b) milk output, (c) utilized starch equivalent, were compared in detail on a farm scale in 1958–60 using a predominantly autumn-calving dairy herd together with ewes and lambs. Full data are given in the form of tables and graphs. Conserved grass was expressed as potential production by using standard conversion factors. There was no clear relationship among the 3 methods where data were compared on a field by field basis (7 fields were used in the study). On a farm system basis, there was a close relationship between (a) and (c). Cow-equivalent days multiplied by 10 was approximately equal to utilized starch equivalent measured in lb. Milk output per feed acre was easy to calculate and was a useful economic measure. Method (c) involved detailed recording and required 2 hr./week, compared with 0·5 hr./week for method (a). It was concluded that measurement of output on a farm system basis, using method (a) as an estimate of stocking rate and method (b) as an economic measure, would be the most useful for commercial dairy farms. Such data would be most valid on specialized dairy farms where recording is not complicated by followers and/or sheep. Effects of stocking rate on production are discussed.—R.B. From *Herbage Abstracts*.

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INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1960

1959	EXPENDITURE	£ s. d.	£ s. d.
£			
2092	Cost of Production of Journal ..		2602 8 2
142	Honoraria to Editor and Assistant Editors		215 9 0
25	Journal, Clerical Assistance ..		30 0 0
111	Stationery and Printing		108 7 9
—	"British Grassland Recording" Expenditure		66 4 5
	Office Expenses:—		
443	Salaries		519 12 8
77	Postages and Telephones ..		73 3 7
16	Rent		— — —
20	Heat and Light		20 0 0
26	Advertising		34 11 11
76	Travelling and Secretarial Expenses		72 6 2
4	Cheque Books and Bank Charges		2 2 0
	Professional Charges:—		
21	Accountancy	26 5 0	
—	Taxation	21 0 0	
			47 5 0
—	8th International and other Congress Expenditure ..		302 8 6
54	Winter Meeting Expenses ..		98 8 4
—	Sundries		4 0 8
	Depreciation Written Off:—		
15	Office Furniture and Equipment	17 15 0	
—	Bedford Van	115 19 7	
			133 14 7
309	Excess of Income over Expenditure for the Year carried to Balance Sheet		226 0 9
£3431			£4556 3 6

1959	INCOME	£ s. d.
£		
1676	Membership Subscriptions ..	1931 13 10
20	Affiliation Fees from County Societies Net Income	2 13 3
1612	Journal and Reprint Sales ..	2343 6 7
78	1960 Summer Meeting—Net Profit	151 8 8
18	Bank Interest Received	— — —
27	Income from Investments	55 2 6
—	Income Tax Recovered	55 13 8
—	Rent Charge written back (1959)	16 5 0
£3431		£4556 3 6

BALANCE SHEET AS AT 31st DECEMBER, 1960

1959 £	LIABILITIES	£ s. d.	£ s. d.
	ACCUMULATED FUND		
	Balance at 1st January, 1960 ..	2926 16 8	
	Add Excess of Income over Expenditure for the year	226 0 9	
2927			3152 17 5
	SUNDRY CREDITORS		
10	Subscriptions received in advance	— — —	
1124	Other Creditors	896 13 2	
1134			896 13 2
£4061			£4049 10 7

1959 £	ASSETS	£ s. d.	£ s. d.
	OFFICE EQUIPMENT, SHELVING AND EQUIPMENT		
	As last Balance Sheet	127 0 0	
	Add Additions during the year	45 15 0	
		172 15 0	
127	*Less* Depreciation at 10% ..	17 15 0	
			155 0 0
	BEDFORD VAN at cost	463 18 6	
—	*Less* Depreciation at 25% ..	115 19 7	
			347 18 11
1948	INVESTMENT—£2000 4¼% British Electricity Stock 1967/69 at cost		1948 10 6
216	SUNDRY DEBTORS		535 8 4
50	ADVANCE for 1962 Summer Meeting		50 0 0
—	ADVANCE for 1961 Summer Meeting		50 0 0
—	ADVANCE for 1961 French Tour ..		108 0 0
1683	CASH AT BANK		834 19 7
37	CASH IN HAND		19 13 3
£4061			£4049 10 7

WE CERTIFY the foregoing Income and Expenditure Account and Balance Sheet to be in accordance with the Books and Vouchers of the Society and with information supplied by the Secretary-Treasurer.

8 Forbury, Reading. *29th March, 1961.*

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2. When submitting an article the author should state the approximate number of words it contains. Articles should be as concise as possible and 1000 to 3500 words in length. Tables and figures should be kept to the minimum necessary for understanding the article. Authors need not give all their data. Instead they should indicate where the full data can be consulted, e.g. in the library of an institute, college or bureau.

3. Each article should begin with an adequate summary which should state briefly: what was done, why it was done, the results obtained and the conclusions drawn. The introduction to the article, which follows the summary, should briefly explain the nature of the problem dealt with and the experimental methods used to attack it. The presentation of experimental data must be concise and their statistical significance indicated, where possible. There should follow a clear statement on the application of the results obtained and/or their relationship to some problem of grassland- or animal-husbandry. Tables, graphs and diagrams should be as few and as simple as possible and must be confined to essential data. Numerical results should be presented either as tables or diagrams, not as both.

4. Articles should be typewritten on one side of the paper, using double spacing and leaving a wide left-hand margin. Pages must be numbered. Tables should be on separate numbered sheets and the places where they are to appear must be indicated in the margin of the text.

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